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WHITSON,

C.R

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Effect of Slope Length on Hill Erosion from  
Phosphate Mine Waste Embankments.

CONDA PARTNERSHIP

*(USU was also involved --  
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EFFECT OF SLOPE LENGTH ON RILL EROSION  
FROM PHOSPHATE MINE WASTE EMBANKMENTS

by

Cyrille R. Whitson and George E. Hart

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## INTRODUCTION

The degradation of watercourses due to surface mining of phosphate ore in southeastern Idaho is a concern of land regulatory and management agencies. The erosion of disturbed land and consequent sediment delivery to sensitive streams and lakes warrants particular attention (Platts and Martin, 1978). Several studies have been conducted to determine the hydrologic properties of mined land in southeastern Idaho, but none have measured erosion rates from overburden waste embankments directly.

The waste embankments demand attention because of their composition and proportions. Waste material removed from the ore pits is dumped, often at the angle-of-repose, onto undisturbed land. After grading, ripping, seeding, and fertilizing, the embankments cover from 10 to 200 acres and have slope lengths approaching 1000 feet.

The USLE, used to predict the average annual soil loss from croplands, postulates a positive relationship between slope length and soil loss per unit area. If the same relationship holds true on these embankments, expensive erosion control measures may be proposed.

A three-year study, involving the U.S. Forest Service, the Conda Mining Partnership, and the Forestry Department at Utah State University, focused on erosion from phosphate mine embankments in southeastern Idaho. The results of the study are presented in this report.

## LITERATURE REVIEW

Prior to 1940, little research had been done to determine the effect of slope length on soil erosion. Duley and Hayes (1932) and Neal (1938) studied the effects of slope gradient on soil erosion, but A.W. Zingg (1940) was the first to address the slope length-erosion relationship. Zingg analyzed the results of laboratory and field plot research, and found that; 1), doubling slope length increased total soil loss 3.03 times, and 2), soil erosion per unit area was proportional to length of slope raised to the 0.6 power. This relationship is illustrated in Figure 1.

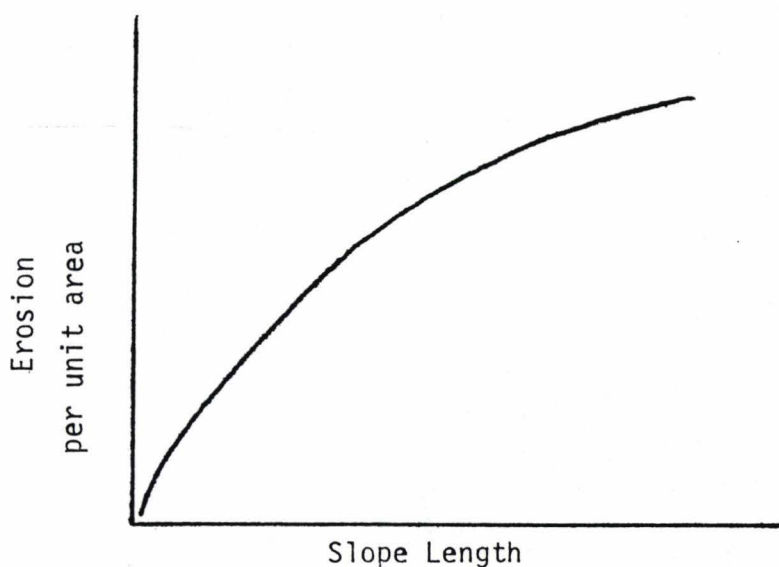


Figure 1. The relationship between erosion and slope length as proposed by Zingg. (Hudson, 1971)

As soil erosion research on agricultural lands continued, the relationship between slope length and erosion became established in the Universal Soil Loss Equation (Wischmeier and Smith, 1978). Statistical analysis of over 10,000 plot-years of

data produced the relationship;  $L = (\lambda / 72.6)^m$ , where  $L$  is a dimensionless factor which describes the ratio of soil loss from a slope of length  $\lambda$ , to that from a 72.6 foot plot under similar conditions. This relationship, as shown in Figure 2, predicts that a 200-foot slope length erodes at a rate twice that of a 50-foot length. The value of the exponent  $m$  varies according to slope gradient. It is generally accepted that  $m = 0.1$  for slopes of 1 percent, at 0.3 for slopes of 3 percent, and at 0.5 for slopes steeper than 5 percent (Dissmeyer and Foster, 1984).

The main objective of this study was to determine the effect of slope length on erosion, but sufficient data were collected to evaluate other hydrologic characteristics of these embankments. Several previous studies have also contributed to the knowledge concerning their hydrologic behavior. Riker, et. al. (1978) studied the slope stability of embankment material, and engineering properties such as compaction, permeability, and shear strength. Chacho (1978) reported on the snow accumulation and erosion from waste dumps. His analysis of erosion, measured by rill-meter, produced no apparent relationship between soil loss and slope length. Kotansky (1985) made a computer-aided hydrologic simulation of a canyon cross-filled with waste material. The infiltration and erosion characteristics of overburden material was also reported by Knopp and Farmer (1980). Their research showed that infiltration and erosion rates varied considerably between two soils on an embankment surface.

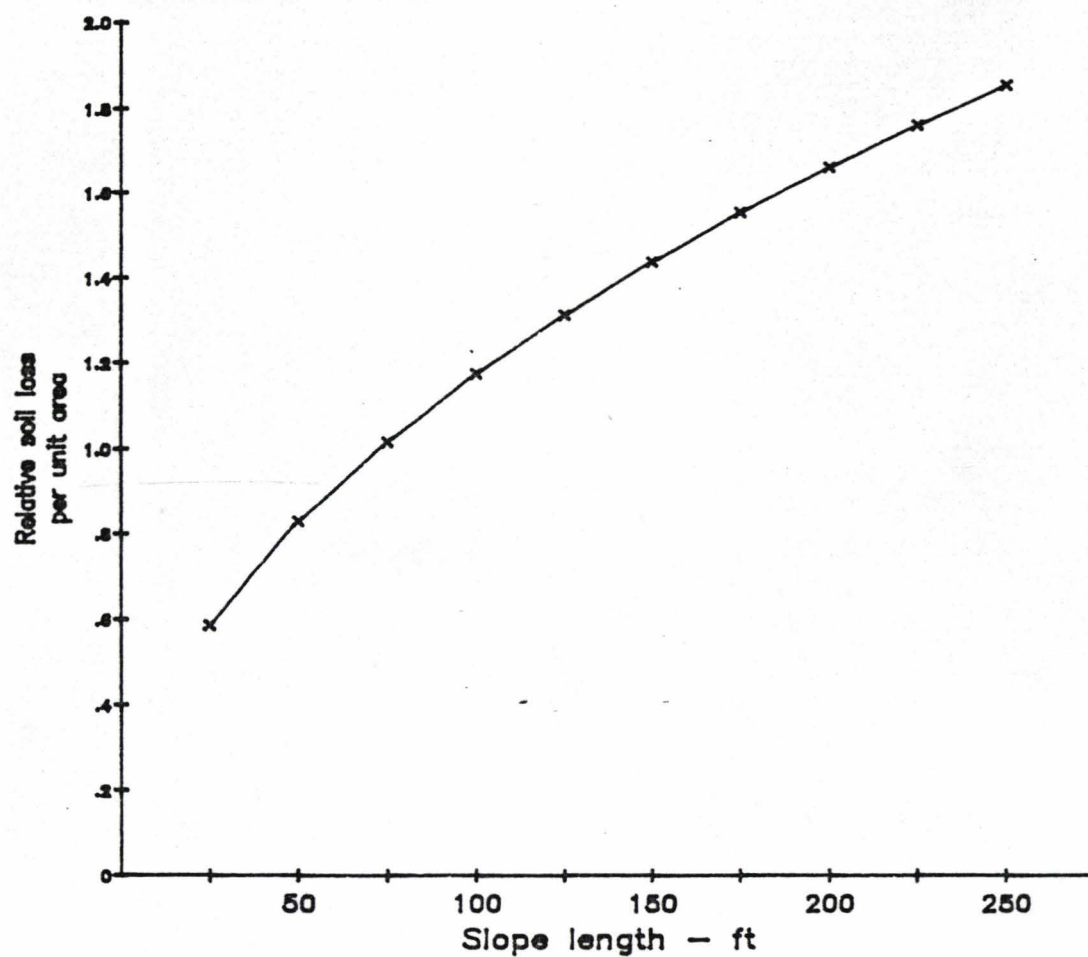


Figure 2. The relationship between slope length and soil loss as predicted by the USLE.

The effect of slope length on erosion per unit area has not been clearly determined on phosphate mine waste embankments. Several land management and regulatory agencies are concerned that soil loss from mine embankments causes sedimentation and contamination of local watercourses. It is this concern which brings about the need for erosion research.

## OBJECTIVES

It is important to determine the slope length - soil loss relationship on phosphate waste embankments so that recommendations for mid-slope drainage structures can be made if needed. The primary objective of this study is to determine this relationship using simulated rainfall. Secondary objectives are to determine other hydrologic properties, such as 1), surface runoff velocities and 2), embankment surface roughness, and its role in the erosion process.

## STUDY SITES

The research was conducted on embankments at the Maybe Canyon mine, about 25 miles northeast of Soda Springs, Idaho. Three embankments were chosen for study (Figure 3). The East Mill site had an east aspect, an elevation of about 7500 feet, and had a good cover of grasses and forbs. The South Maybe site had virtually no vegetative cover, a north aspect, and an elevation of 7200 feet. The slope at the Champ site was also void of vegetation, had an east aspect, and had an elevation of about 6300 feet. Slope gradients ranged from 24 to 33 percent, and averaged 28 percent.

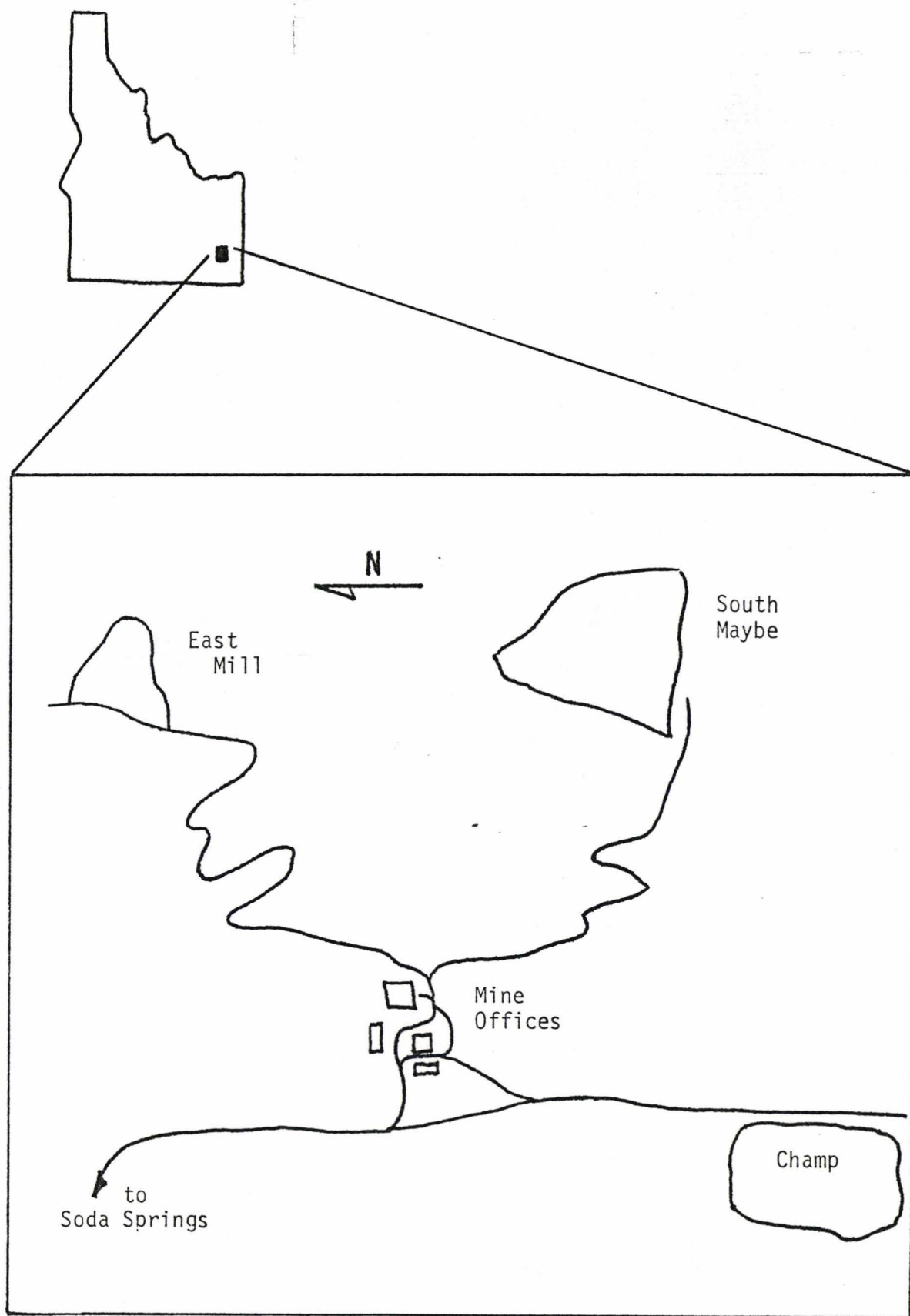


Figure 3. Locations of study sites in southeastern Idaho.  
Not to scale.

## METHODS

### Rainfall Simulator:

The use of rainfall simulators allows for the measurement of erosion at predetermined sites and times. Simulators eliminate the spatial and temporal uncertainties associated with natural rainfall events. A simulator, of the same design as that developed at Colorado State University (Lusby, 1977), was used because it was necessary to apply rainfall on very long slopes, up to 200 feet (61 m) in length. The length of the "standard" USLE plot is about 73 feet (22 m) and the fundamental relationships between length and unit area soil loss were carried out on slopes of about this length. By adding additional sprinkler risers, the simulator can be extended over slopes of several hundred feet, provided that sufficient volumes of water and pump capacity are available.

In order to estimate soil loss caused by high intensity storms under summer conditions, thirteen simulated rainfall events were applied to pairs of 12-foot-wide (3.7 m) plots varying in length from 50 to 200 feet (15 to 61 m). The simulator had three major components: 1) a water reservoir, in this case three, 4000 gallon ( $17.5 \text{ m}^3$ ) rubber bladders; 2) a pump capable of supplying 300 gallons per minute ( $1.3 \text{ m}^3/\text{min}$ ); and 3) a series of risers which sprinkled rain over a pair of erosion

plots. Figure 4 is a plan layout of two erosion plots and the simulator setup. Work by Neff (1979) showed that complete rainfall coverage of plots is achieved with this arrangement. Neff (1979) also studied the drop size distribution (Figure 5), kinetic energy, wind effects, and water-use efficiency of this simulator. At an application rate of two inches per hour (5.1 cm/hr), this simulator produces a kinetic energy about 55 percent that of natural rainfall, but as the intensity drops below two inches per hour, the kinetic energy approaches that for natural rainfall at the same intensity (Neff, 1979).

#### Plot Construction:

A transit was used to determine the plot boundaries. Steel rods were placed at 25-foot (7.6 m) intervals and connected with twine to mark the edges. Ten-foot (3 m) long aluminum sheets, folded into an inverted "V" were laid flush to the ground along the marked borders. This type of border was used because of the gravelly nature of the embankment surfaces, and the great difficulty of driving metal sheets into the stony surface. The inside of each plot frame was packed and tamped with soil, then tackified using a soil binder to make the borders leak-proof. At the plot bases, the side borders were angled to concentrate surface runoff into the aluminum type-H flumes. The flumes were dug into the embankment so that the drop inlet was horizontal and

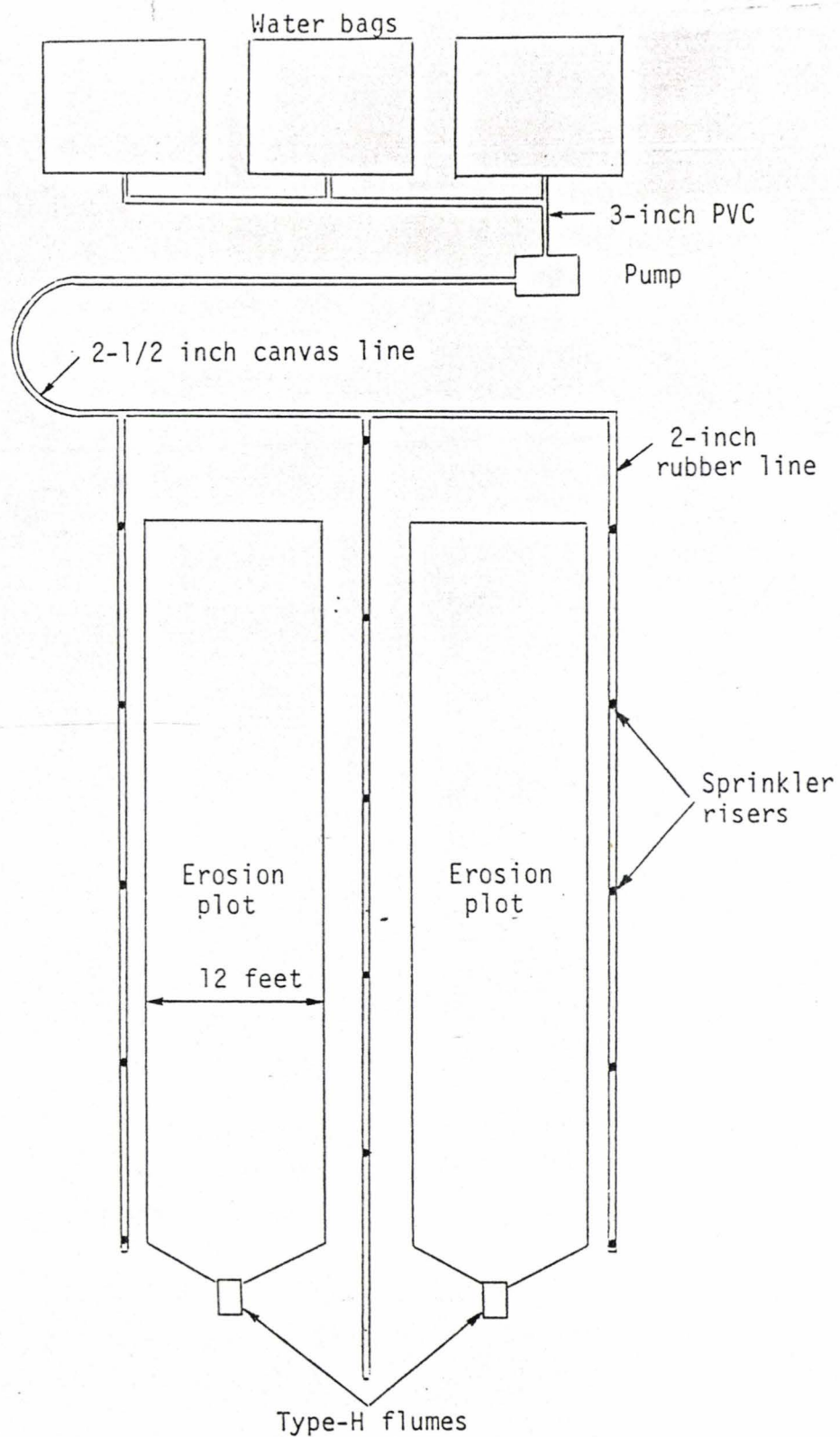


Figure 4. Erosion plots and rainfall simulator setup.  
Not to scale.

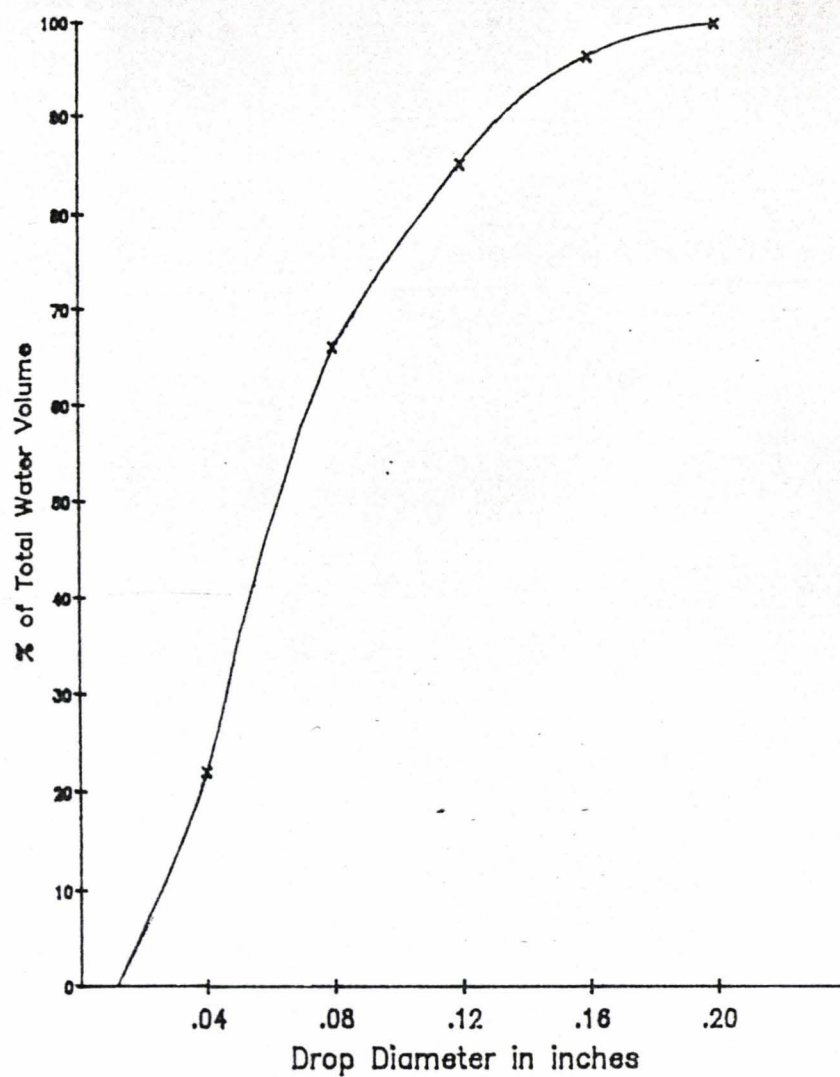


Figure 5. Drop size distribution of the simulator applying rain at 2 in/hr. (Neff, 1979).

flush with the plot surface. Extra layers of tackifier were used to secure the areas where surface runoff concentration was greatest.

#### Measurement of Surface Characteristics:

Before each simulator run, four to six samples of surface soil were collected per plot, and antecedent moisture was determined gravimetrically from these samples. Six-to-twelve photos per plot were taken of a one by two foot (30 by 61 cm) rectangular steel frame placed on the plot surface. The photos were then enlarged by projecting the slide onto a gridded board, and these components of surface cover were estimated as percentages;

Live vegetation - any photosynthesizing material standing upright.

Litter - any dead vegetative material lying in contact with the plot surface.

Rocks - any stone having dimensions larger than three inches (7.6 cm).

Gravel - material larger than soil particles ( 0.079 inches, 2 mm ), but smaller than three inches (7.6 cm).

Soil - material smaller than 0.079 inches (2 mm).

Samples of the surface six to eight inches (15 to 20 cm) of embankment material were taken for each plot. A sieve analysis was used to determine the percentage of the fine earth fraction.

#### Measurement of Runoff and Erosion:

Rainfall was measured using 30 evenly-distributed wedge gages. Average rainfall depths for each plot were found using the isohyetal method. Rainfall intensity was calculated by dividing the depth of rainfall by the storm duration. During rainfall events, all sprinkler heads and risers were checked for proper spin and pressure. Runs were made while winds were at a minimum.

When a measureable depth of runoff occurred, the manometer was read and a one quart (one liter) runoff subsample was taken. This was repeated at one-minute intervals while runoff increased. Subsamples and manometer readings were taken at two-minute intervals as the plots reached runoff equilibrium. When rain stopped, runoff tapered off almost immediately, and readings were again taken at one-minute intervals. After a run, the "self-cleaning" flumes were emptied of sediment. The dry weight of this sediment was added directly to final calculations of soil loss. Final observations such as rill development were noted, and the wedge gages were checked for rainfall depths.

The runoff subsamples were taken back to Logan, the volume of runoff was measured and the samples were allowed to settle for at least 24 hours. The supernatant was then siphoned off. The remaining sediments were placed in small pans and dried overnight at 247°F (105°C). Each subsample was weighed and the original

concentration calculated in parts per million. Subsamples from the Champ site had extremely high concentrations (up to 400,000 ppm), and the procedure described in Agricultural Handbook 224 (USDA-SEA, 1979, pg. 304) was used to adjust them. Sediment loss for each time interval was calculated by multiplying each concentration by the discharge that occurred during that one or two minute interval. This is a sample equation:

$$(3000 \text{ ppm})(.02 \text{ cfs})(120 \text{ secs})(62.4 \text{ lbs/cu.ft.})$$

$$= 0.4493 \text{ pounds sediment/two minutes}$$

or

$$(3000 \text{ ppm})(.034 \text{ m}^3/\text{min})(120 \text{ secs})(.8 \text{ kg/m}^3)$$

$$= 0.204 \text{ kilograms sediment/two minutes.}$$

Conversion to tons/acre (tonnes/ha) was made from the measured plot area.

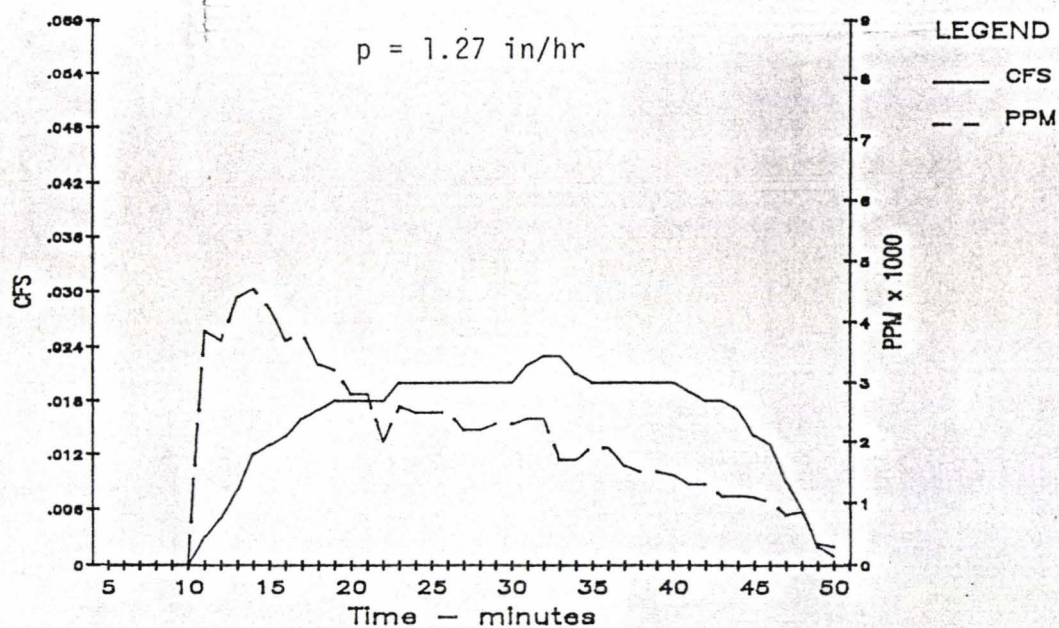
Runoff velocity measurements were made using dyes or salt and a conductivity meter. The dye or salt was spread across plots at 25-foot (7.6 m) intervals up the slope and travel times taken by stopwatch. Three slugs of dye were applied to interill areas on long plots to determine flow velocities outside of established rills.

## RESULTS AND DISCUSSION:

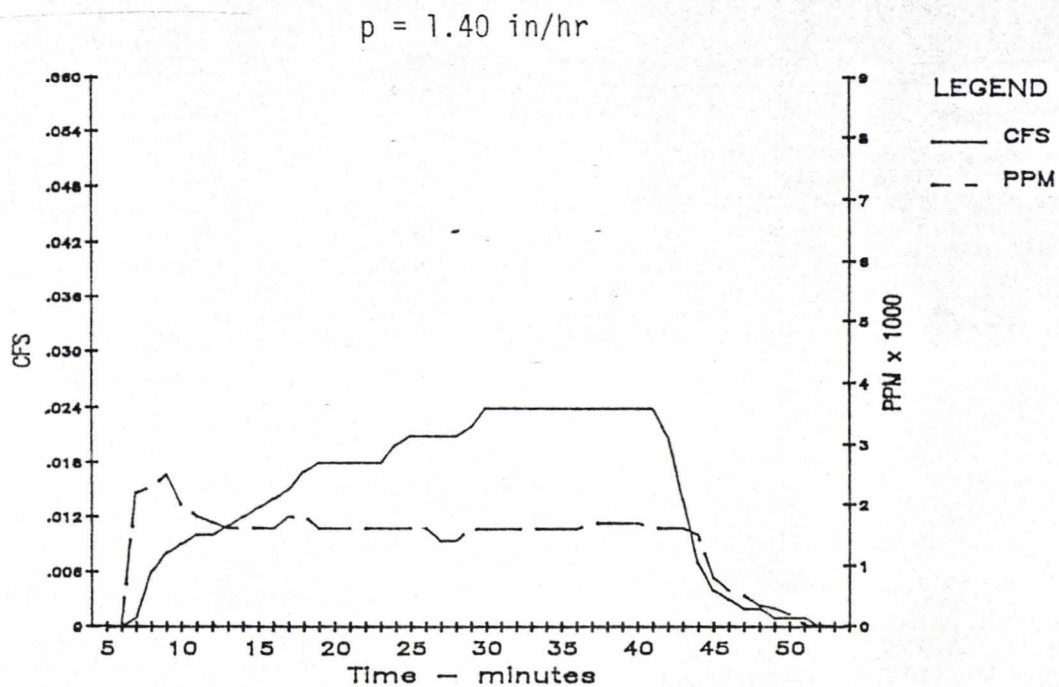
### Surface Hydrology:

Artificial rainfall durations averaged 47 minutes and ranged from 31 to 58 minutes. The average rainfall intensity was 1.65 inches per hour (4.2 cm/hr), and the mean depth was 1.3 inches (3.3 cm). According to Hershfield (1961), an event of 1.3 inches per hour occurs about once every 100 years, on the average, in southeastern Idaho, so these simulated rainfalls represented the 100-year event or larger. Unpublished data (personal communication, Bryan Williams, Intermountain Forest and Range Experiment Station, Logan, Utah, 1985) indicates that the average summer storm in the study area is .14 inches (.36 cm) precipitation.

Ponding began soon after rainfall started. A period of five-to-twelve minutes was consistently observed between start of rainfall and start of runoff. As rainfall continued, areas further upslope began contributing to overland flow. Generally, but not always, runoff equilibrium was achieved as shown in the hydrographs for each plot (Figures 6a-t). The figures show discharge, in cubic feet per second (cfs), and sediment concentration, in parts per million (ppm), plotted against time. It can be noted that the runoff from the 50, 73, 90, and 100 foot (15, 22, 27, and 30 m) plots reached a period of sustained peak flow, subsiding rapidly after rainfall stopped. This is seen clearly in nine of eleven runs on shorter plots, but in only

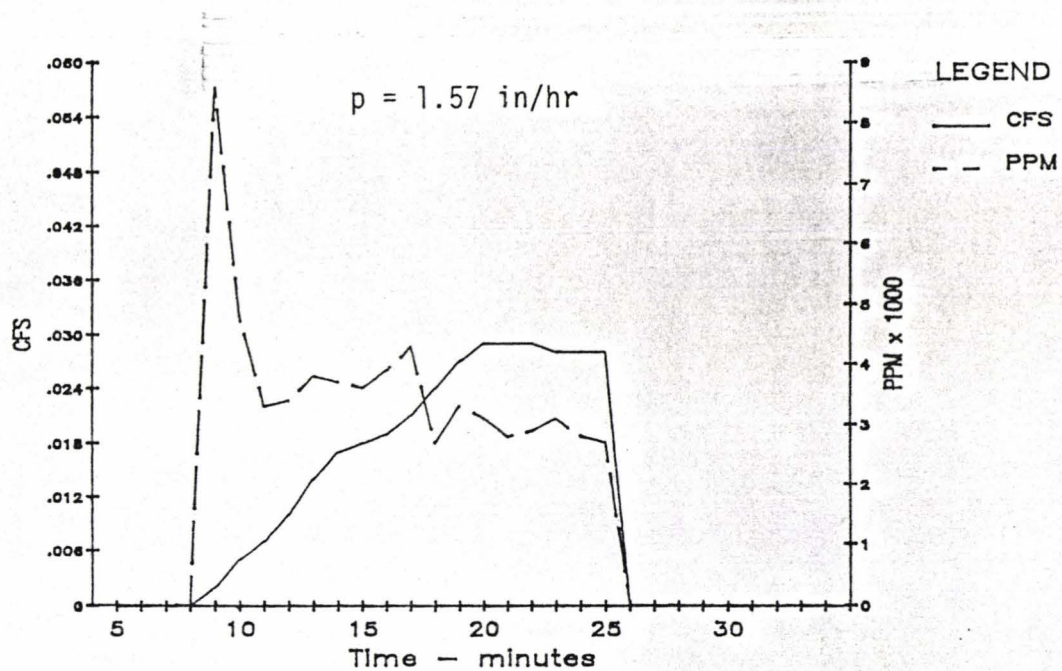


(a)

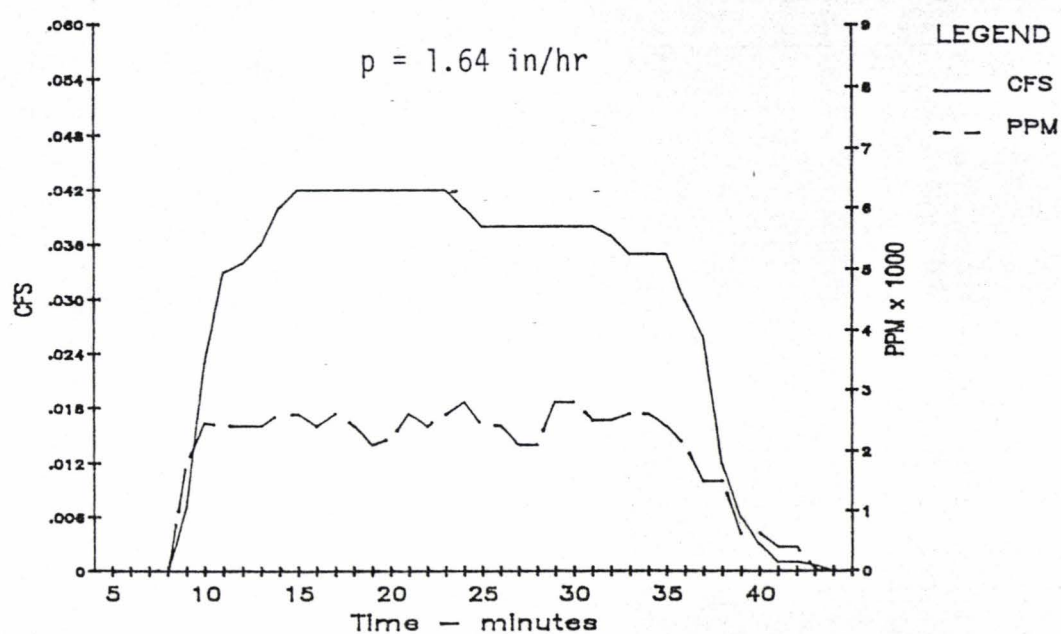


(b)

Figure 6. Runoff hydrographs and sedigraphs from East Mill 1984.  
 (a) plot 50a (b) plot 50b.



(c)



(d)

Figure 6. Runoff hydrographs and sedigraphs from East Mill 1984.  
 (c) plot 100a (d) plot 100b.

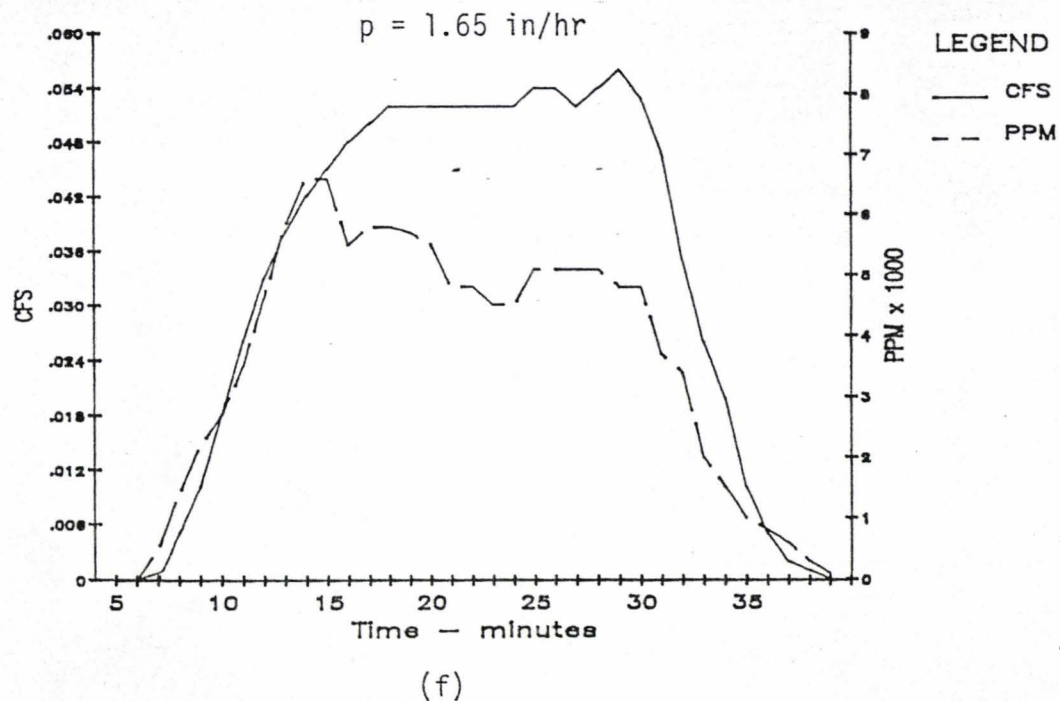
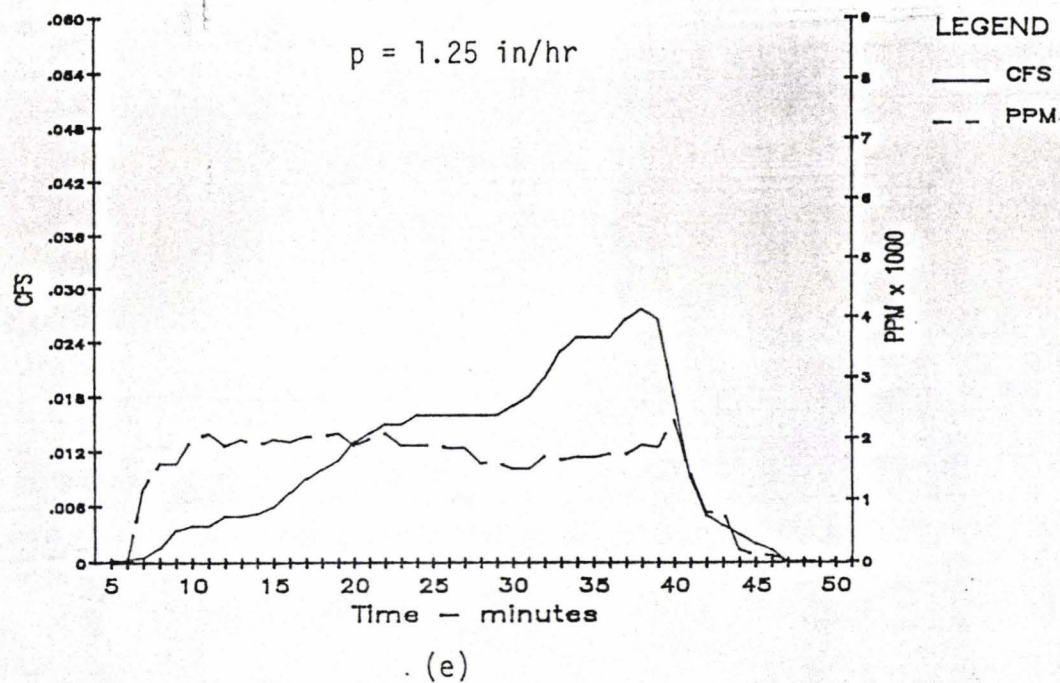


Figure 6. Runoff hydrographs and sedigraphs from East Mill 1984.  
(e) plot 150a (f) plot 150b.

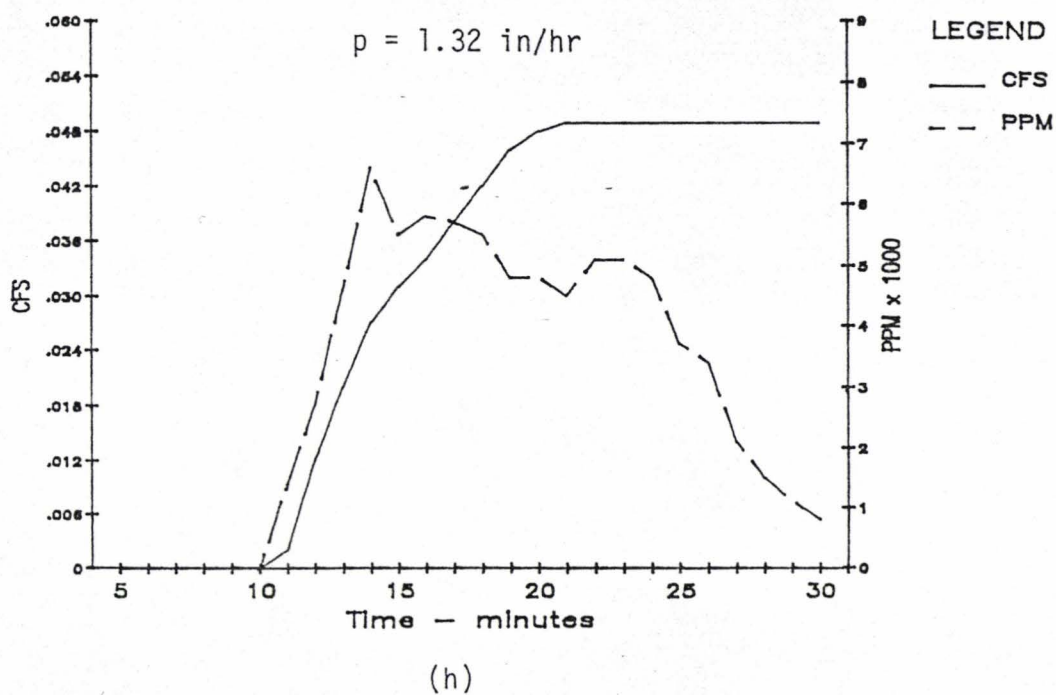
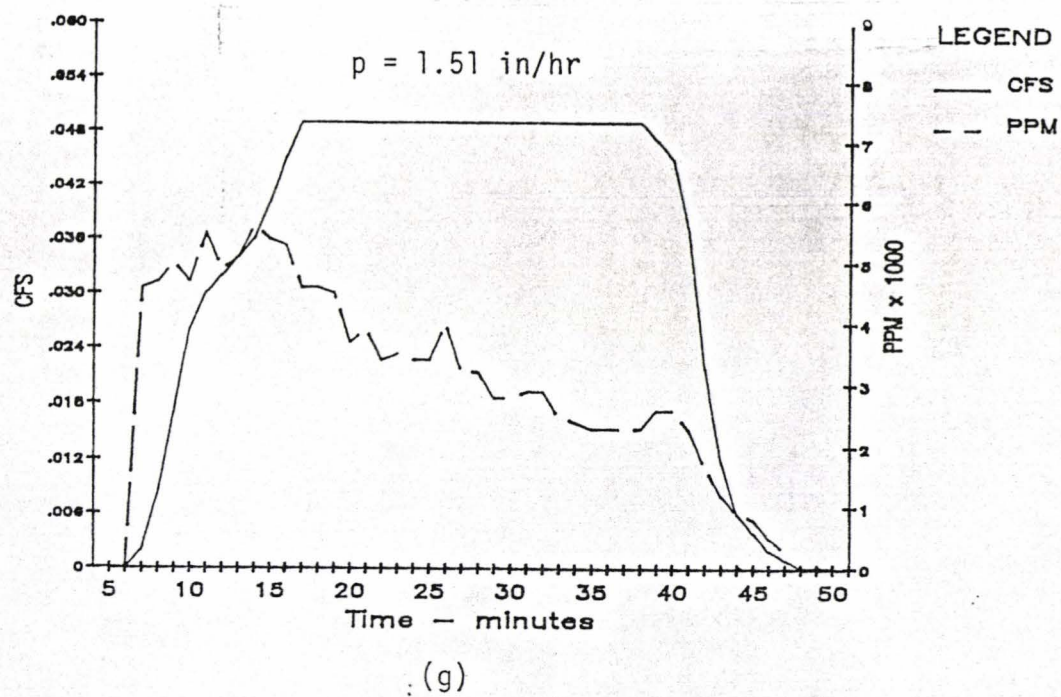
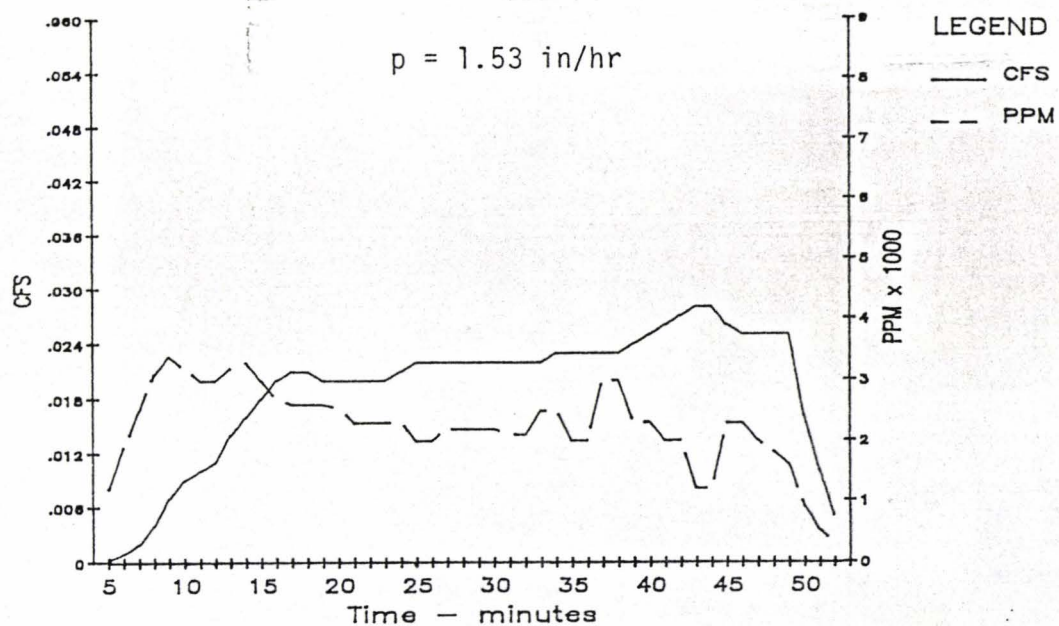
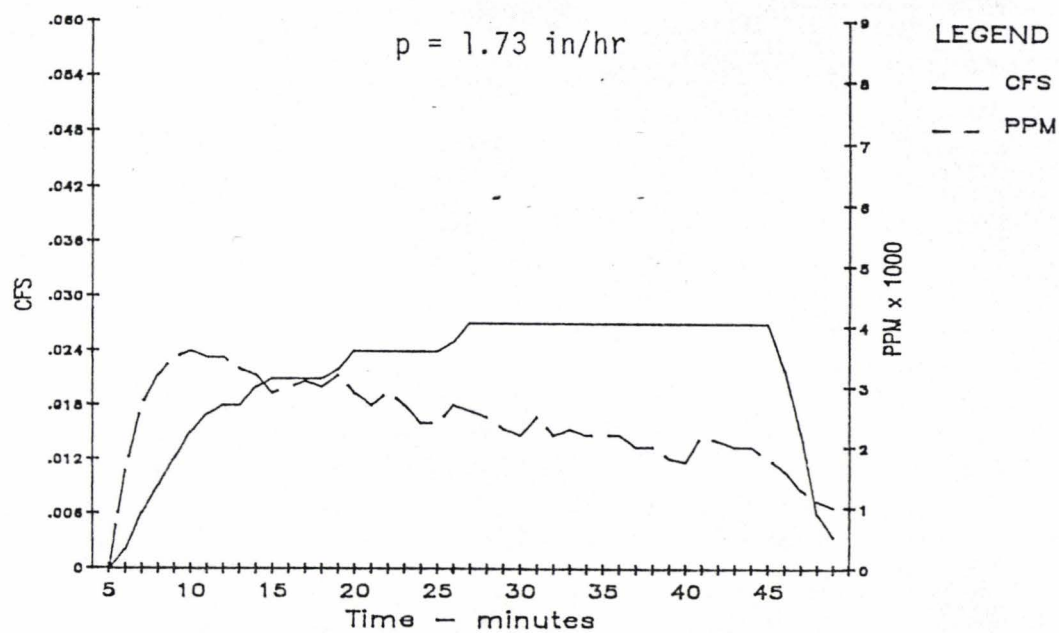


Figure 6. Runoff hydrographs and sedigraphs from East Mill 1984.  
(g) plot 200a (h) plot 200b.

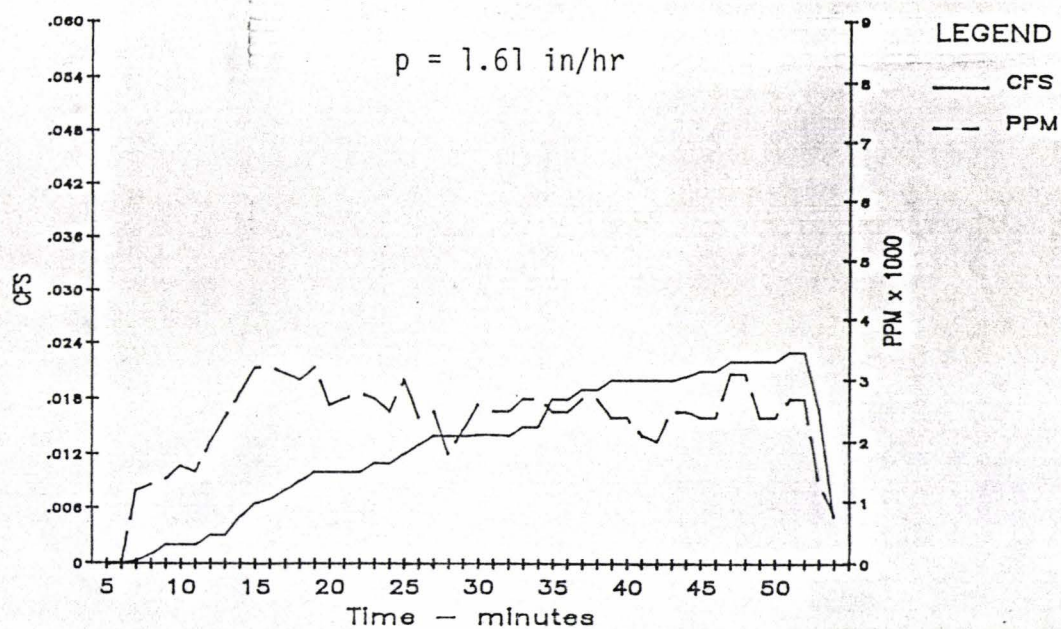


(i)

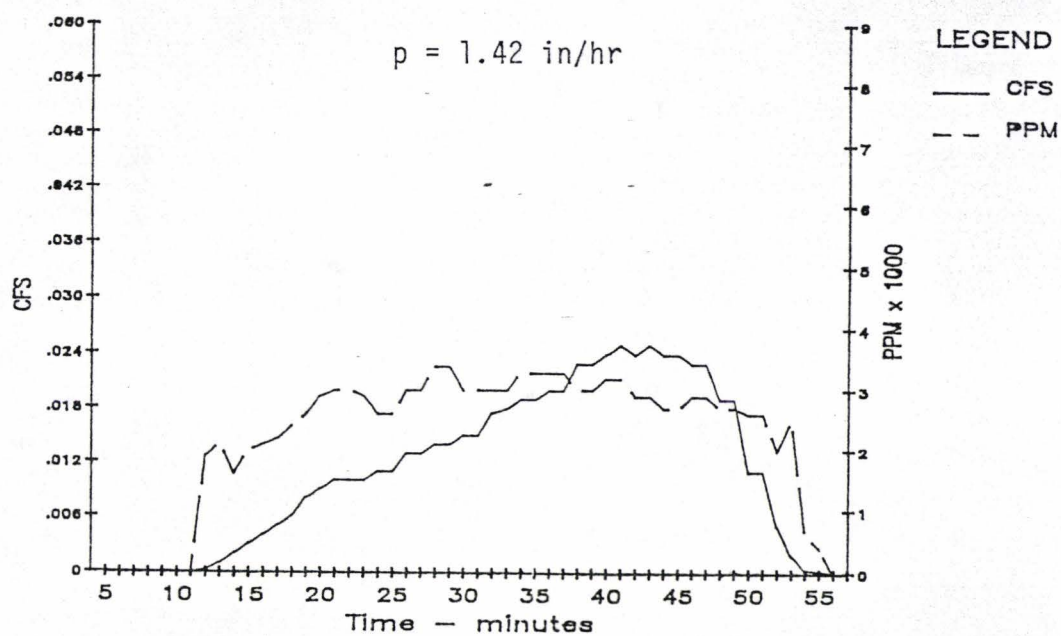


(j)

Figure 6'. Runoff hydrographs and sedigraphs from East Mill 1985.  
 (i) plot 73a (j) plot 73b.



(k)



(l)

Figure 6. Runoff hydrographs and sedigraphs from East Mill 1985.  
 (k) plot 150a (l) plot 150b.

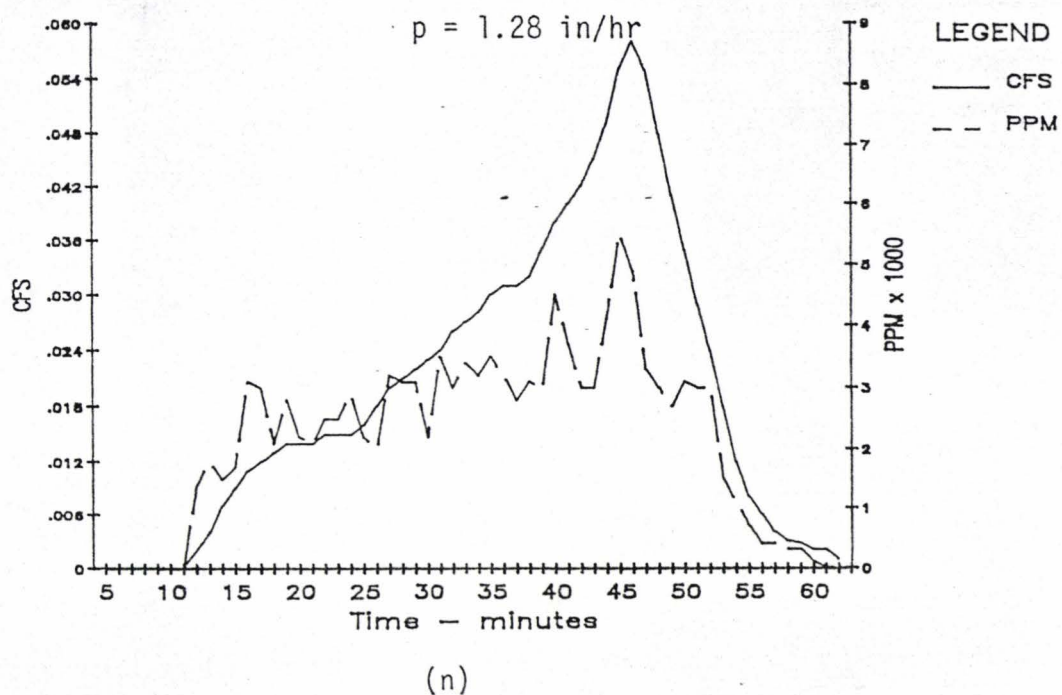
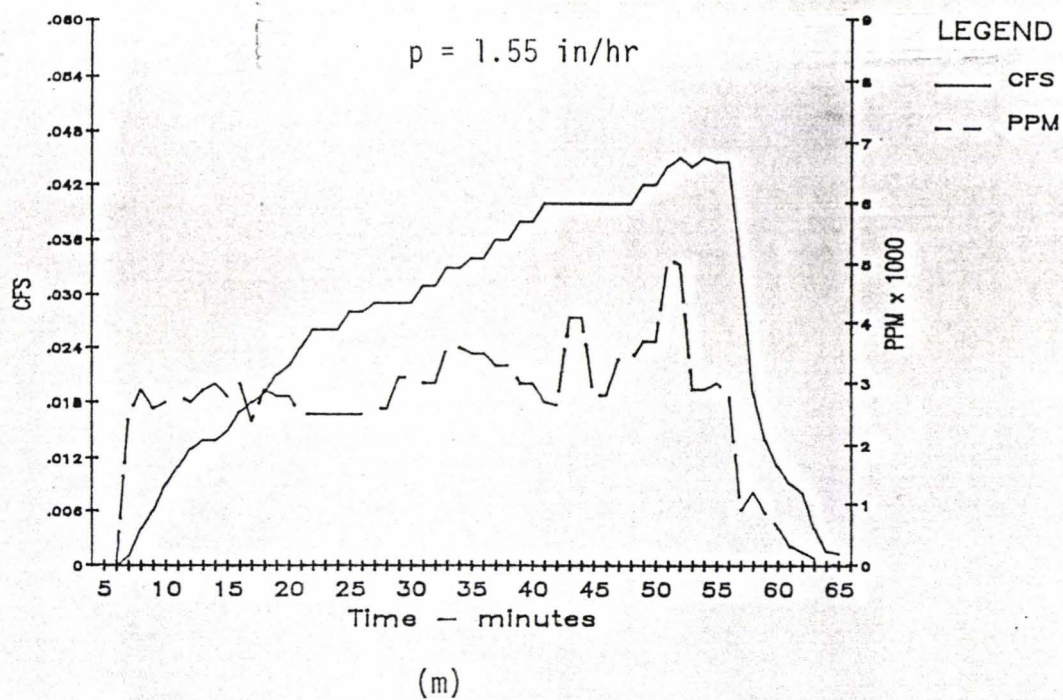
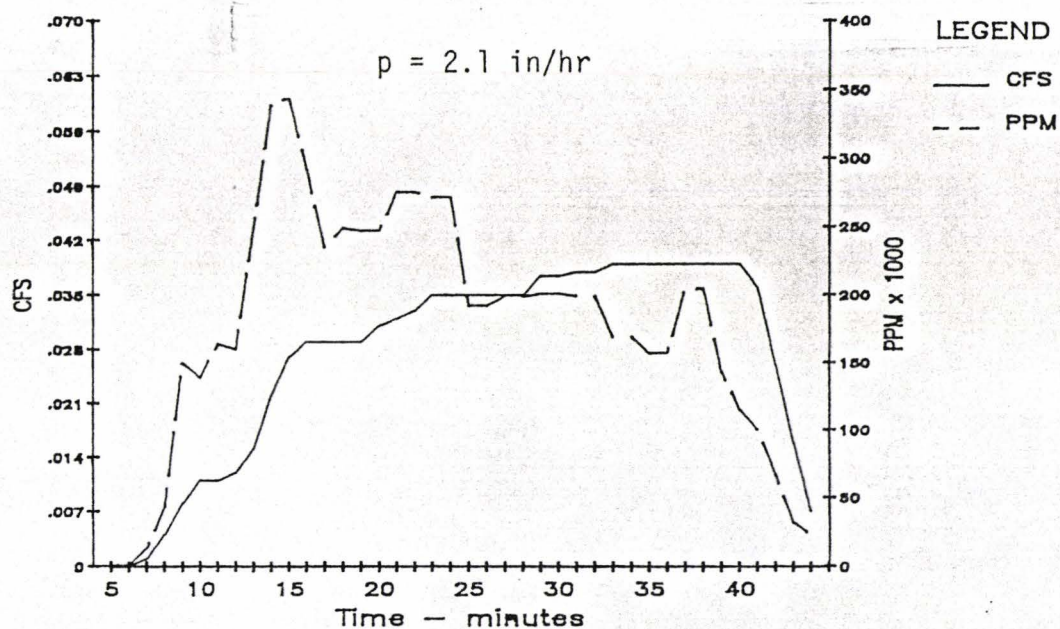
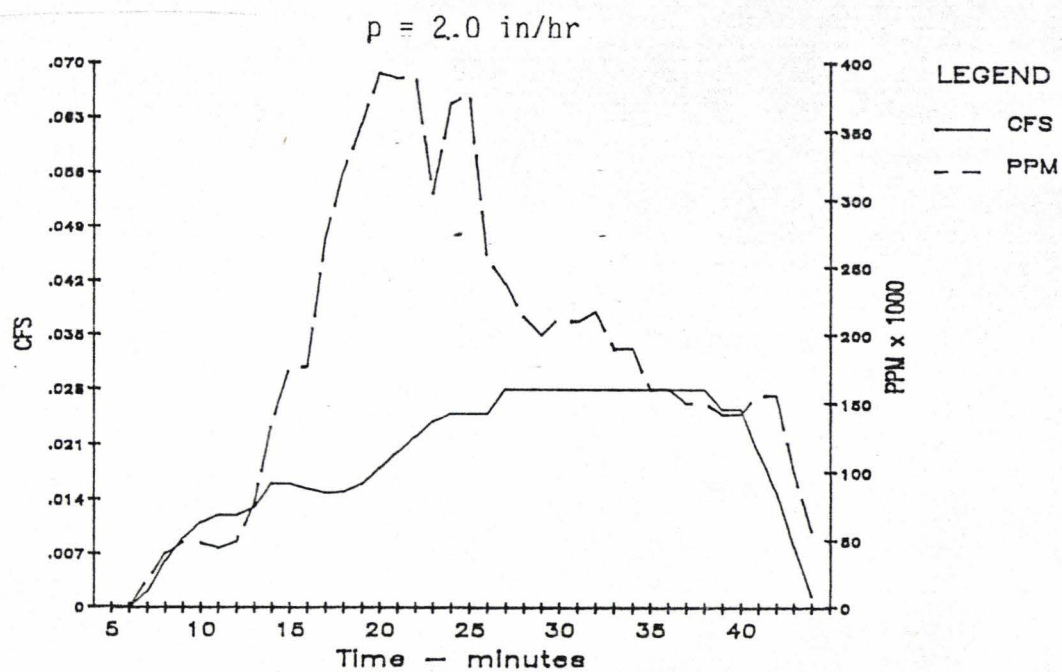


Figure 6. Runoff hydrographs and sedigraphs from East Mill 1985.  
 (m) plot 200a (n) plot 200b.

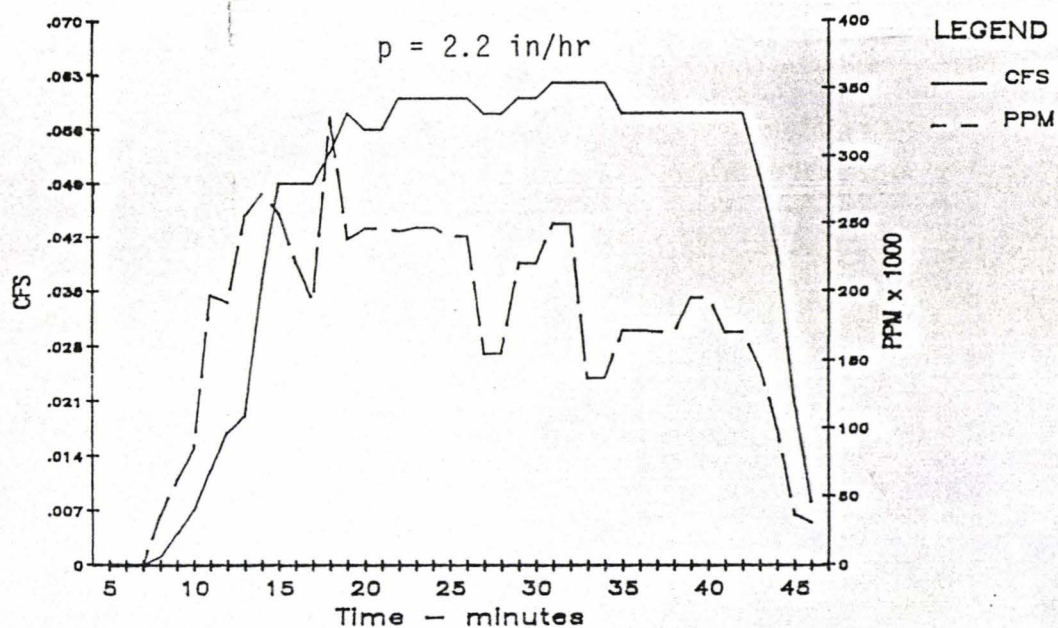


(o)

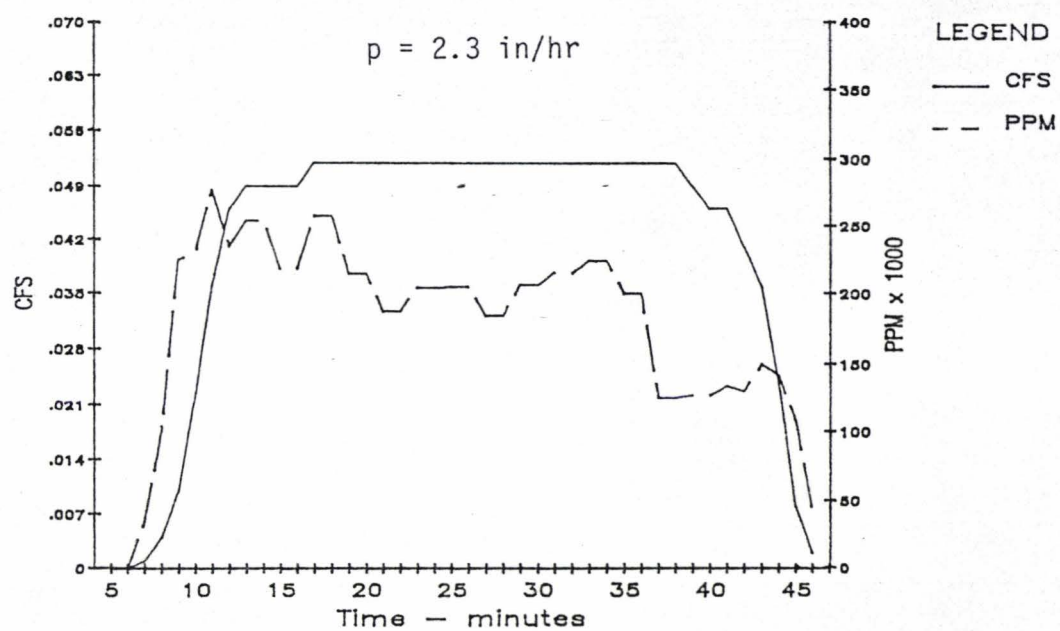


(p)

Figure 6. Runoff hydrographs and sedigraphs from Champ 1986.  
(o) plot 50a (p) plot 50b.



(q)



(r)

Figure 6 . Runoff hydrographs and sedigraphs from Champ 1986.  
 (q) plot 73a (r) plot 73b.

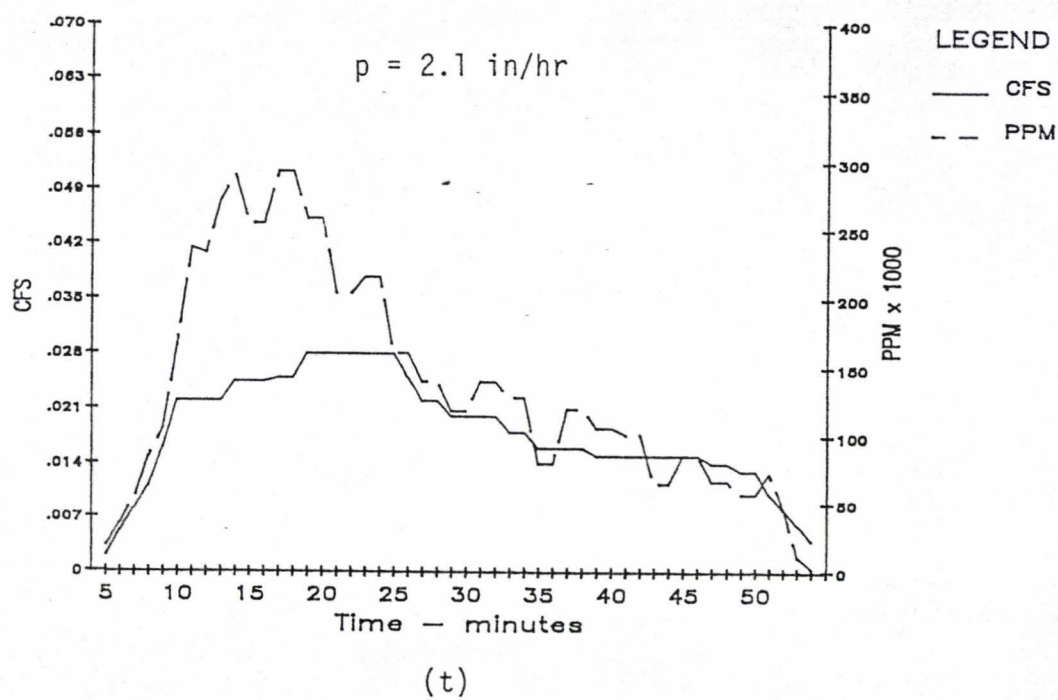
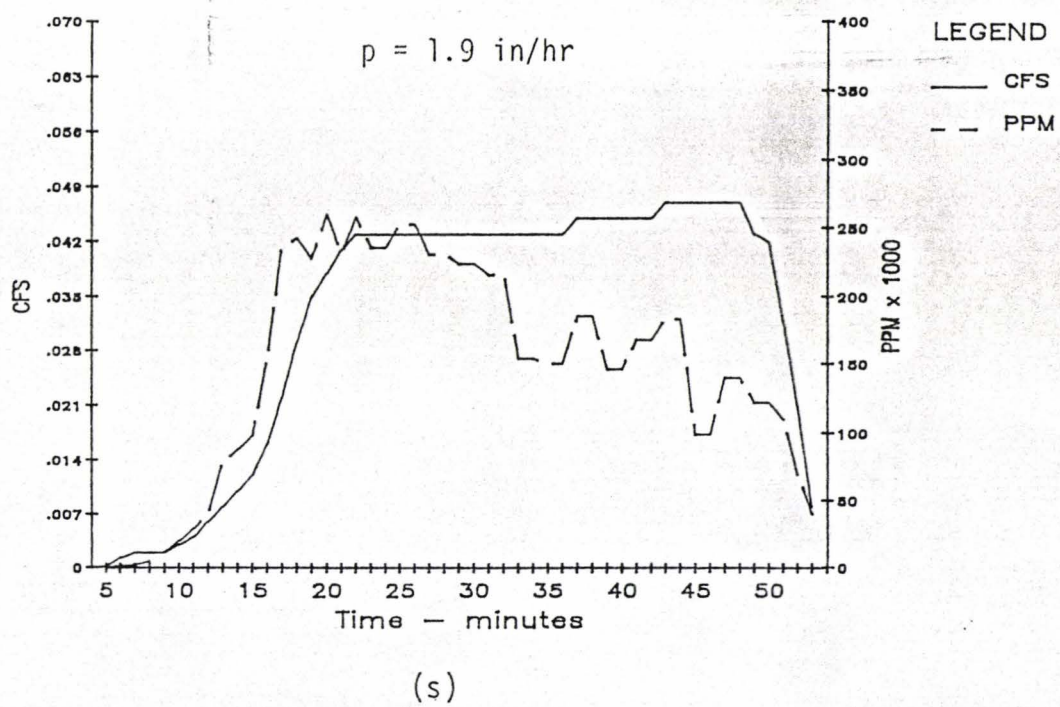


Figure 6. Runoff hydrographs and sedigraphs from Champ 1986.  
 (s) plot 90a (t) plot 90b.

three of eight runs made on 150 and 200 foot (46 and 61 m) plots. Plots of shorter length tended to reach an equilibrium where runoff-to-rainfall ratios (Q/P) were high and infiltration rates were low. Tables 1a,1b,1c, and 1d are summaries of the surface hydrology for all three sites. The Q/P ratios averaged over 67 percent on plots 50 to 100 feet (15 to 30 m) long. The 150 and 200-foot (46 and 61 m) plots had Q/P ratios averaging 33 percent. This is because rainfall duration was not sufficient on long plots to bring about flow equilibrium. Had rainfall been applied for considerably longer periods, sustained periods of peak flow may have been observed on more of the long plots.

Runoff-to-rainfall ratios (Q/P) also showed site specific differences. Q/P ratios at the Champ site averaged 71 percent, while plots of similar length at East Mill averaged 63 percent. It was consistently noted that these ratios decreased with increased slope length, and increased with storm duration.

Average peak flows differed little between Champ (0.043 cfs, 0.073 m<sup>3</sup>/min) and East Mill (0.036 cfs, 0.061 m<sup>3</sup>/min), but large differences were observed in runoff sediment concentrations. The average peak sediment concentration at East Mill was 4,400 parts per million. This average was 310,000 parts per million on the Champ plots.

Several hydrographs show flow levels changing erratically after about twelve minutes of runoff (e.g. plot 73-a at Champ,

Table 1a. Summary of surface hydrology, East Mill, 1984.

| Plot | Area<br>(ft <sup>2</sup> ) <sup>1</sup> | Slope<br>(%) | Moist.<br>(%) | P<br>(in) <sup>2</sup> | p<br>(in<br>hr) <sup>3</sup> | Q-time<br>(min) | Q-peak<br>(cfs) <sup>4</sup> | Q/P<br>(%) | Soil Loss<br>(T/A) <sup>5</sup> | Soil Loss<br>(T/A/R) <sup>6</sup> |
|------|-----------------------------------------|--------------|---------------|------------------------|------------------------------|-----------------|------------------------------|------------|---------------------------------|-----------------------------------|
| 50a  | 640                                     | 27           | 10            | .87                    | 1.27                         | 41              | .023                         | 84         | .181                            | .029                              |
| 50b  | 640                                     | 27           | 11            | .96                    | 1.40                         | 42              | .024                         | 80         | .140                            | .019                              |
| 100a | 1250                                    | 27           | 7             | .91                    | 1.57                         | 17*             | .029                         | 36         | .077                            | .010                              |
| 100b | 1288                                    | 27           | 8             | .96                    | 1.64                         | 37              | .042                         | 63         | .164                            | .019                              |
| 150a | 1789                                    | 27           | 12            | .79                    | 1.25                         | 42              | .028                         | 26         | .040                            | .007                              |
| 150b | 1979                                    | 27           | 4             | .85                    | 1.65                         | 33              | .056                         | 48         | .225                            | .029                              |
| 200a | 2589                                    | 27           | 11            | .95                    | 1.51                         | 42              | .049                         | 43         | .162                            | .020                              |
| 200b | 2450                                    | 27           | 7             | .67                    | 1.32                         | 19*             | .049                         | 52         | .102                            | .020                              |

\* Measurement of runoff on these plots was stopped due to leakage at the flume.

- 1 To convert to m<sup>2</sup>, multiply by 10.76
- 2 To convert to cm<sup>2</sup>, multiply by 2.54
- 3 To convert to cm/hr, multiply by 2.54
- 4 To convert to m<sup>3</sup>/min, multiply by 1.7
- 5 To convert to tonnes/ha, multiply by 2.24
- 6 To convert to tonnes/ha/R, multiply by .132

Table 1b. Summary of surface hydrology, East Mill, 1985.

| Plot            | Area<br>(ft <sup>2</sup> ) <sup>1</sup> | Slope<br>(%) | Moist.<br>(%) | P<br>(in) <sup>2</sup> | p<br>(in/hr) <sup>3</sup> | Q-time<br>(min) | Q-peak<br>(cfs) <sup>4</sup> | Q/P<br>(%) | Soil Loss<br>(T/A) <sup>5</sup> | Soil Loss<br>(T/A/R) <sup>6</sup> |
|-----------------|-----------------------------------------|--------------|---------------|------------------------|---------------------------|-----------------|------------------------------|------------|---------------------------------|-----------------------------------|
| 73a             | 920                                     | 27           | 10            | 1.17                   | 1.53                      | 49              | .028                         | 63         | .201                            | .020                              |
| 73b             | 950                                     | 27           | 10            | 1.33                   | 1.73                      | 47              | .027                         | 56         | .210                            | .016                              |
| 150a            | 1834                                    | 27           | 11            | 1.37                   | 1.61                      | 51              | .023                         | 19         | .079                            | .006                              |
| 150b            | 2017                                    | 27           | 10            | 1.23                   | 1.42                      | 45              | .025                         | 18         | .071                            | .007                              |
| 200a            | 2612                                    | 27           | 12            | 1.57                   | 1.55                      | 61              | .045                         | 28         | .148                            | .011                              |
| 200b            | 2492                                    | 27           | 11            | 1.09                   | 1.28                      | 51              | .058                         | 30         | .129                            | .016                              |
| 1984,1985 AVG.: |                                         | 27           | 10            | 1.05                   | 1.48                      | 41              | .036                         | 46         | .138                            | .016                              |

- <sup>1</sup> To convert to m<sup>2</sup>, multiply by 10.76
- <sup>2</sup> To convert to cm<sup>2</sup>, multiply by 2.54
- <sup>3</sup> To convert to cm/hr, multiply by 2.54
- <sup>4</sup> To convert to m<sup>3</sup>/min, multiply by 1.7
- <sup>5</sup> To convert to tonnes/ha, multiply by 2.24
- <sup>6</sup> To convert to tonnes/ha/R, multiply by .132

Table 1c. Summary of surface hydrology, South Maybe, 1985.

| Plot  | Area<br>(ft <sup>2</sup> ) <sup>1</sup> | Slope<br>(%) | Moist.<br>(%) | P<br>(in) <sup>2</sup> | p<br>(in<br>hr) <sup>3</sup> | Q-time<br>(min) | Q-peak<br>(cfs) <sup>4</sup> | Q/P<br>(%) | Soil Loss<br>(T/A) <sup>5</sup> | Soil Loss<br>(T/A/R) <sup>6</sup> |
|-------|-----------------------------------------|--------------|---------------|------------------------|------------------------------|-----------------|------------------------------|------------|---------------------------------|-----------------------------------|
| 50a   | 612                                     | 28           | 1             | 1.8                    | 1.9                          | 0               | 0                            | 0          | 0                               | 0                                 |
| 50b   | 630                                     | 28           | 1             | 1.9                    | 1.9                          | 0               | 0                            | 0          | 0                               | 0                                 |
| 100a  | 1214                                    | 30           | 1             | 1.2                    | 1.3                          | 0               | 0                            | 0          | 0                               | 0                                 |
| 100b  | 1226                                    | 30           | 1             | 1.0                    | 1.1                          | 0               | 0                            | 0          | 0                               | 0                                 |
| 50a   | 640                                     | 24           | 4             | 1.7                    | 1.8                          | 0               | 0                            | 0          | 0                               | 0                                 |
| 50b   | 632                                     | 24           | 4             | 1.5                    | 1.6                          | 0               | 0                            | 0          | 0                               | 0                                 |
| AVG.: |                                         | 27           | 2             | 1.5                    | 1.6                          | 0               | 0                            | 0          | 0                               | 0                                 |

- <sup>1</sup> To convert to m<sup>2</sup>, multiply by 10.76
- <sup>2</sup> To convert to cm<sup>2</sup>, multiply by 2.54
- <sup>3</sup> To convert to cm/hr, multiply by 2.54
- <sup>4</sup> To convert to m<sup>3</sup>/min, multiply by 1.7
- <sup>5</sup> To convert to tonnes/ha, multiply by 2.24
- <sup>6</sup> To convert to tonnes/ha/R, multiply by .132

Table 1d. Summary of surface hydrology, Champ, 1986.

| Plot  | Area<br>(ft <sup>2</sup> ) <sup>1</sup> | Slope<br>(%) | Moist.<br>(%) | P<br>(in) <sup>2</sup> | p<br>(in<br>hr) <sup>3</sup> | Q-time<br>(min) | Q-peak<br>(cfs) <sup>4</sup> | Q/P<br>(%) | Soil Loss<br>(T/A) <sup>5</sup> | Soil Loss<br>(T/A/R) <sup>6</sup> |
|-------|-----------------------------------------|--------------|---------------|------------------------|------------------------------|-----------------|------------------------------|------------|---------------------------------|-----------------------------------|
| 50a   | 631                                     | 30           | 3             | 1.4                    | 2.1                          | 40              | .039                         | 87         | 29.7                            | 1.75                              |
| 50b   | 630                                     | 30           | 3             | 1.4                    | 2.0                          | 40              | .028                         | 64         | 21.9                            | 1.43                              |
| 73a   | 870                                     | 33           | 3             | 1.6                    | 2.2                          | 40              | .062                         | 95         | 35.9                            | 1.87                              |
| 73b   | 875                                     | 33           | 3             | 1.7                    | 2.3                          | 40              | .052                         | 85         | 35.7                            | 1.64                              |
| 90a   | 1075                                    | 33           | 1             | 1.7                    | 1.9                          | 49              | .048                         | 63         | 23.1                            | 1.29                              |
| 90b   | 1100                                    | 33           | 1             | 1.9                    | 2.1                          | 50              | .028                         | 31         | 10.2                            | 0.46                              |
| AVG.: |                                         | 31           | 2             | 1.7                    | 2.1                          | 43              | .043                         | 71         | 26.1                            | 1.41                              |

- <sup>1</sup> To convert to m<sup>2</sup>, multiply by 10.76
- <sup>2</sup> To convert to cm<sup>2</sup>, multiply by 2.54
- <sup>3</sup> To convert to cm/hr, multiply by 2.54
- <sup>4</sup> To convert to m<sup>3</sup>/min, multiply by 1.7
- <sup>5</sup> To convert to tonnes/ha, multiply by 2.24
- <sup>6</sup> To convert to tonnes/ha/R, multiply by .132

and plots 200a and 150b at East Mill). It is likely that this variation was caused by errors in measurement rather than actual changes in runoff rate. It was noted that even small deviations in manometer levels caused noticeable variation in hydrograph shape.

Time was allotted during several runs to determine runoff velocities using dyes or salt injections. Results of those experiments are shown in Table 2. These velocities predominantly represent rill flow. Interill flow was much slower. Limited data suggest that movement through rills was two to three times faster than interill velocity (Table 2). A clear relationship linking greater flow velocities with longer slopes was not observed. This may be attributed to the surface roughness of the embankments, where vegetation, litter, and gravel obstructed interill flow. These data agree with previous work (Kramer and Meyer, 1969) which showed that even low mulch rates (1/4 t/a, .56 tonnes/ha) appreciably reduced runoff velocity and erosion rates. At mulch rates of one-eighth and one-quarter ton per acre (.28 and .56 tonnes/ha), Kramer and Meyer found that runoff velocities averaged 0.44 feet per second (0.13 m/sec).

#### Surface Conditions of Embankments:

The East Mill and South Maybe sites were dominated by fractured rocky material; but, because the ore at the Champ site was located beneath the valley floor, the embankment materials there

Table 2. Runoff velocities from East Mill and Champ sites.

| East Mill 1984, 1985 |                            |     |                      |                                |     |                                    |
|----------------------|----------------------------|-----|----------------------|--------------------------------|-----|------------------------------------|
| Plot                 | Segment length<br>(ft) (m) |     | Travel time<br>(sec) | Rill velocity<br>(ft/sec)(m/s) |     | Interill velocity<br>(ft/sec)(m/s) |
| 73a                  | 25                         | 7.6 | 30                   | .8                             | .24 |                                    |
| 73a                  | 50                         | 15  | 93                   | .5                             | .15 |                                    |
| 73b                  | 25                         | 7.6 | 54                   | .4                             | .12 |                                    |
| 73b                  | 50                         | 15  | 138                  | .3                             | .09 |                                    |
| 150a                 | 25                         | 7.6 | 45                   | .6                             | .18 |                                    |
| 150a                 | 25                         | 7.6 | 44                   | .6                             | .18 | .3 .09                             |
| 150a                 | 50                         | 15  | 155                  | .3                             | .09 |                                    |
| 150a                 | 50                         | 15  | 82                   | .6                             | .18 | .2 .06                             |
| 150a                 | 75                         | 23  | 165                  | .4                             | .12 |                                    |
| 150b                 | 25                         | 7.6 | 60                   | .4                             | .12 |                                    |
| 150b                 | 50                         | 15  | 80                   | .6                             | .18 |                                    |
| 200a                 | 25                         | 7.6 | 45                   | .6                             | .18 |                                    |
| 200a                 | 25                         | 7.6 | 27                   | .9                             | .27 | .3 .09                             |
| 200a                 | 50                         | 15  | 75                   | .7                             | .21 |                                    |
| 200a                 | 50                         | 15  | 58                   | .9                             | .27 |                                    |
| 200a                 | 75                         | 23  | 130                  | .6                             | .18 |                                    |
| 200a                 | 100                        | 30  | 178                  | .6                             | .18 |                                    |
| 200b                 | 25                         | 7.6 | 52                   | .5                             | .15 |                                    |
| 200b                 | 50                         | 15  | 90                   | .6                             | .18 |                                    |
| AVG:                 |                            |     |                      | .6                             | .18 | .3 .09                             |
| Champ 1986           |                            |     |                      |                                |     |                                    |
| 50a                  | 25                         | 7.6 | 44                   | .6                             | .18 |                                    |
| 50a                  | 25                         | 7.6 | 48                   | .5                             | .15 |                                    |
| 50b                  | 25                         | 7.6 | 50                   | .5                             | .15 |                                    |
| 50b                  | 25                         | 7.6 | 50                   | .5                             | .15 |                                    |
| 73a                  | 25                         | 7.6 | 40                   | .6                             | .18 |                                    |
| 73a                  | 25                         | 7.6 | 56                   | .4                             | .12 |                                    |
| 73a                  | 50                         | 15  | 75                   | .7                             | .21 |                                    |
| 73b                  | 25                         | 7.6 | 41                   | .6                             | .18 |                                    |
| 73b                  | 25                         | 7.6 | 62                   | .4                             | .12 |                                    |
| 73b                  | 50                         | 15  | 108                  | .5                             | .15 |                                    |
| AVG:                 |                            |     |                      | .5                             | .15 |                                    |

were mostly alluvial sediments. The surface characteristics of each embankment are shown in tables 3a, 3b, and 3c. The three sites chosen for the study varied greatly in surface composition. East Mill, in its third (1984) and fourth (1985) growing season, showed much higher vegetation and litter cover - 36 percent - and an intermediate proportion of gravel - 52 percent - when compared to the other two sites. South Maybe and Champ sites were similar to each other with respect to vegetation and litter cover - two and three percent respectively - but soil and gravel cover densities differed greatly. South Maybe had five percent bare soil, while Champ had 64 percent.

Regression analysis revealed that the percentage of the surface covered by bare soil was the primary factor in determining erosion ( $R^2 = 85\%$ ,  $r = .93$ ). The slope of the least squares trend line was significantly different from zero at the 95% confidence level. Gravel cover showed a strong negative correlation with soil loss ( $r = -.63$ ), but the slope of the trend line did not differ significantly from zero. Table 4 shows the degree of association between each of the cover factors and soil loss using data from all sites. These correlations improved considerably when the data from South Maybe were excluded.

Table 3a. Surface Characteristics of East Mill site.

| Plot | -----% Cover----- |        |       |        |      | Embankment<br>material<br>-----Upper 15cm----- |      |
|------|-------------------|--------|-------|--------|------|------------------------------------------------|------|
|      | Veg               | Litter | Rocks | Gravel | Soil | >2mm                                           | <2mm |
| 50a  | 8                 | 19     | 5     | 60     | 8    | 66                                             | 34   |
| 50b  | 10                | 25     | 6     | 53     | 6    | 53                                             | 47   |
| 73a  | 3                 | 25     | 5     | 58     | 8    | 63                                             | 37   |
| 73b  | 9                 | 28     | 3     | 51     | 9    | 69                                             | 31   |
| 100a | 9                 | 25     | 5     | 47     | 16   | 71                                             | 29   |
| 100b | 13                | 22     | 2     | 57     | 7    | 66                                             | 34   |
| 150a | 9                 | 30     | 5     | 50     | 7    | 65                                             | 35   |
| 150b | 8                 | 32     | 5     | 48     | 7    | 63                                             | 37   |
| 200a | 9                 | 27     | 3     | 52     | 8    | 69                                             | 31   |
| 200b | 8                 | 28     | 2     | 52     | 10   | 67                                             | 33   |
| AVG. | 9                 | 27     | 4     | 52     | 8    | 66                                             | 34   |

Table 3b. Surface characteristics of South Maybe site.

| Plot       | -----% Cover----- |        |       |        |      | Embankment<br>material<br>-----Upper 15cm----- |      |
|------------|-------------------|--------|-------|--------|------|------------------------------------------------|------|
|            | Veg               | Litter | Rocks | Gravel | Soil | >2mm                                           | <2mm |
| 50a chert  | 1                 | 0      | 7     | 88     | 4    | 72                                             | 28   |
| 50b chert  | 2                 | 0      | 7     | 89     | 2    | 69                                             | 31   |
| 100a chert | 2                 | 0      | 6     | 86     | 6    | 77                                             | 23   |
| 100b chert | 2                 | 0      | 9     | 84     | 5    | 69                                             | 31   |
| 50a shale  | 4                 | 0      | 9     | 82     | 5    | 68                                             | 32   |
| 50b shale  | 3                 | 0      | 9     | 81     | 7    | 77                                             | 23   |
| AVG.       | 2                 | 0      | 8     | 85     | 5    | 72                                             | 28   |

Table 3c. Surface characteristics of Champ site.

| Plot | -----% Cover----- |        |       |        |      | Embankment<br>material<br>-----Upper 15cm----- |      |
|------|-------------------|--------|-------|--------|------|------------------------------------------------|------|
|      | Veg               | Litter | Rocks | Gravel | Soil | >2mm                                           | <2mm |
| 50a  | 3                 | 0      | 1     | 32     | 64   | 63                                             | 37   |
| 50b  | 4                 | 0      | 3     | 30     | 64   | 65                                             | 35   |
| 73a  | 3                 | 0      | 2     | 31     | 63   | 66                                             | 34   |
| 73b  | 3                 | 0      | 3     | 32     | 64   | 70                                             | 30   |
| 90a  | 4                 | 0      | 4     | 30     | 63   | 72                                             | 28   |
| 90b  | 3                 | 0      | 2     | 32     | 63   | 69                                             | 31   |
| AVG. | 3                 | 0      | 2     | 31     | 64   | 68                                             | 32   |

Table 4 . Correlation between cover types and observed soil loss from all plots.

| <u>Stat</u> | -----Cover Type----- |               |              |               |             |
|-------------|----------------------|---------------|--------------|---------------|-------------|
|             | <u>Veg</u>           | <u>Litter</u> | <u>Rocks</u> | <u>Gravel</u> | <u>Soil</u> |
| r           | -.37                 | -.53          | -.44         | -.63          | .93         |

A multiple regression of soil loss and these five cover types produced this equation: Tons/acre soil loss =

$$10 - 0.24 \text{ Veg} - 0.14 \text{ Litt} - 0.21 \text{ Rock} - 0.11 \text{ Grav} + 0.33 \text{ Soil}.$$

These results were not unlike those found by Stein, et.al. (1983, p. 105). They found erodibility of mine spoils was measurably lower on areas of fractured shale overburden. They advised that:

It would be advantageous from an erosion control standpoint to leave graded shaley overburden material on the surface. This type of overburden has a much lower erodibility potential than any other surface.

This shaley overburden was similar to the material found on one area of South Maybe, where no runoff occurred, and on parts of East Mill where little soil loss was observed. The high soil loss rates at the Champ site were due primarily to the lack of this gravel - dominated surface, and more exposed soil.

#### Surface Erosion:

Soil losses for all three sites are shown in Tables 1a, 1b, 1c, and 1d, where plot number refers to the length of each plot.

Average soil loss from East Mill plots was .138 tons/acre/storm (.309 tonnes/ha/storm), with a standard error of .015 t/a/storm (.034 tonnes/ha/storm). New rills did not form, and existing rills did not deepen. Small rills became active, but interill areas showed little sign of overland flow, especially on upper plot portions.

The small soil losses seen at East Mill may be explained by several points. First, the embankment was protected by vegetation established over a three to four-year period. In combination with surface litter and gravel, this live vegetation slowed runoff and prohibited notable erosion. Second, the embankment surface had little bare soil available for transport. Third, the storm events were not of sufficient duration to attain similar hydrologic efficiency on long plots as well as short plots. This may also help explain why the correlation between slope length and soil loss was poor. In combination, these three traits caused a resistance of the embankment surface to dispersion, splashing, abrasion, and transporting forces of rainfall and runoff.

The slopes at South Maybe did not erode. Unlike East Mill, these slopes had very little vegetative or litter cover. Antecedent soil moisture was extremely low. The absence of erosion at South Maybe can be attributed primarily to the lack of erodible material. With five percent bare soil and 93 percent rock and gravel, surface erosion at this site would seem unlikely

in the absence of a storm event with a long return period under much wetter conditions.

The Champ site, located in Dry Valley, was selected for study as being representative of a freshly-revegetated embankment. In fall 1985, it was graded, ripped, and seeded to grasses. Slope lengths were shorter than on the other sites and contained a high proportion of alluvial sediments. This provided conditions which should have favored high erosional losses. The area studied was only a few acres in size, and permitted maximum plot lengths of only 90 feet (27 m).

Large erosion rates occurred from the three simulated rainfall events, as expected from the surface conditions of the slope: a large proportion of the surface covered by bare soil, low amounts of surface rock and gravel, steep slopes, no vegetation, and no surface litter. Soil losses averaged 26.1 t/a/storm (58.5 tonnes/ha/storm), with a standard error of 4.0 t/a/storm (9 tonnes/ha/storm). Rainfall rapidly saturated the surface, composed of 64 percent bare soil. Runoff typically began about six minutes after the start of rain and increased quickly. It was noted during all three runs at the Champ site that the entire plot areas contributed to runoff. Sediment concentrations were similar on the 50 (15m), 73 (22m), and 90 (27m) foot plots, but discharge values were considerably lower on the 90 foot plots. Average peak flows from the 73-foot (22 m) plots were .057 cfs

(.097 m<sup>3</sup>/min), while the mean on the 90 foot (27 m) plots was inherent in the type-H flumes. Sediment blocked the inlet to the manometer tube several times on the 90 foot (27 m) plots, and possibly skewed the observed discharge values.

The erosion produced at the Champ site, almost 200 times the rate found at East Mill, provides a reasonably good indication of the worst-possible soil loss case at the Maybe Canyon mine.

### Slope Length - Erosion Relationships:

Long and steep slopes are intuitively more erodible than shorter slopes of lower gradient. This relationship was not clearly demonstrated, however, on the three embankments studied. Regression analysis was applied to data from all 26 plots to determine the slope length - erosion relationship. The least-squares trend line through the data had a positive intercept and a negative slope. The regression equation was;  $\text{Tons/acre} = 13.48 - 0.072 (\text{Length})$ . Slope length showed a weak negative correlation ( $r = -0.32$ ,  $R^2 = 6.7\%$ ) with soil loss. Using only the data from East Mill and Champ, this correlation improved ( $r = -.5$ ,  $R^2 = 20.4\%$ ), but the slope of the trend line was still not significantly different from zero at the 99% confidence level. At the East Mill site, the correlation between soil loss and slope length was  $-0.31$  and the adjusted- $R^2$  was only about two percent. This relationship at the East Mill site is shown in Figure 7. The regression equation was;  $\text{Tons/acre} = 0.175 - 0.000317 \text{ Length}$ .

Determining the soil loss per unit R (rainfall erosion index) for each plot made it possible to examine slope length - erosion relationships without conflicting variables. The plots at East Mill averaged  $.016 \text{ tons/acre/R}$  ( $.036 \text{ tonnes/ha/R}$ ), while Champ plots averaged  $1.4 \text{ tons/acre/R}$  ( $3.14 \text{ tonnes/ha/R}$ ). The relationship between slope length and erosion per unit R was negative ( $R^2 = 22\%$ ,  $r = -0.51$ ), and the regression equation was;  $\text{Tons/acre/R} = 0.74 - 0.004 (\text{Length})$ . The slope of the regression

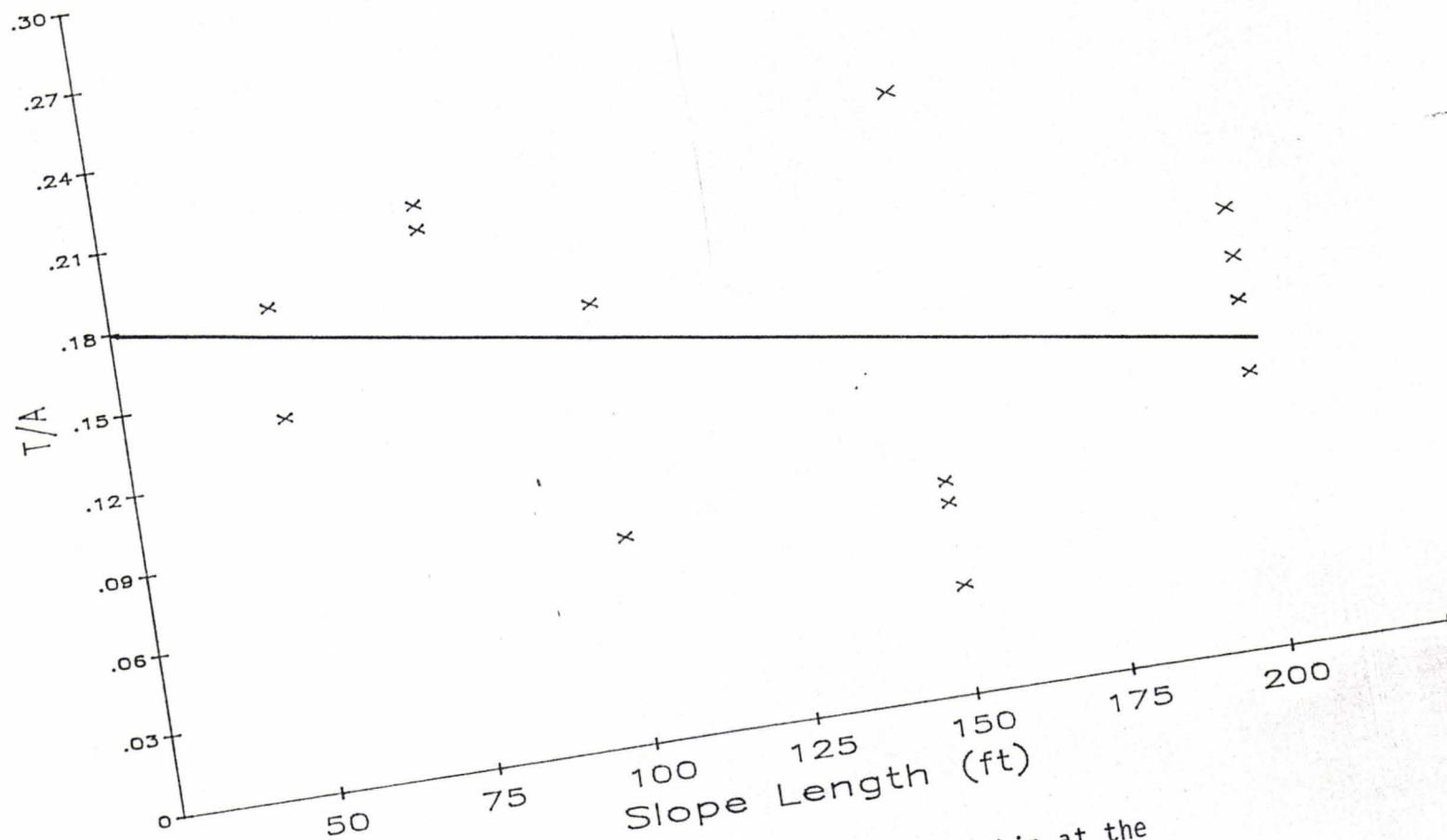


Figure 7. Slope length - erosion relationship at the East Mill site.

line was significantly below zero at the 95% confidence level, so prediction of soil loss using this regression line may be appropriate.

Erosion per unit area at East Mill showed a weak negative correlation with slope length, but total erosion showed a consistent increase corresponding to slope length, as shown in Figure 8.

The value of the length factor in the USLE is determined as  $(/72.6)^m$  where  $m$  has a value of 0.5 for slopes steeper than five percent (Wischmeier and Smith, 1978). Analysis of the data collected from East Mill and Champ, however, indicates that use of the exponent  $m = 0.5$  is not appropriate for these embankments. Empirical review of the data suggests that the value of  $m$  under these conditions is closer to -0.1. Figure 9 illustrates expected values for  $L$  using the exponent 0.5 and the least-squares fit to data from East Mill. The procedure used in calculating this least-squares fit is shown in the appendix.

Instead of proposing a change in  $L$ -exponent values in the use of the USLE under all conditions, I would conclude, rather, that other factors on phosphate mine waste embankments, such as surface roughness, depression storage and coarse rock content, are more important than slope length in affecting soil loss. This information may be of use for those interested in predicting erosion from sites having characteristics similar to those studied here.

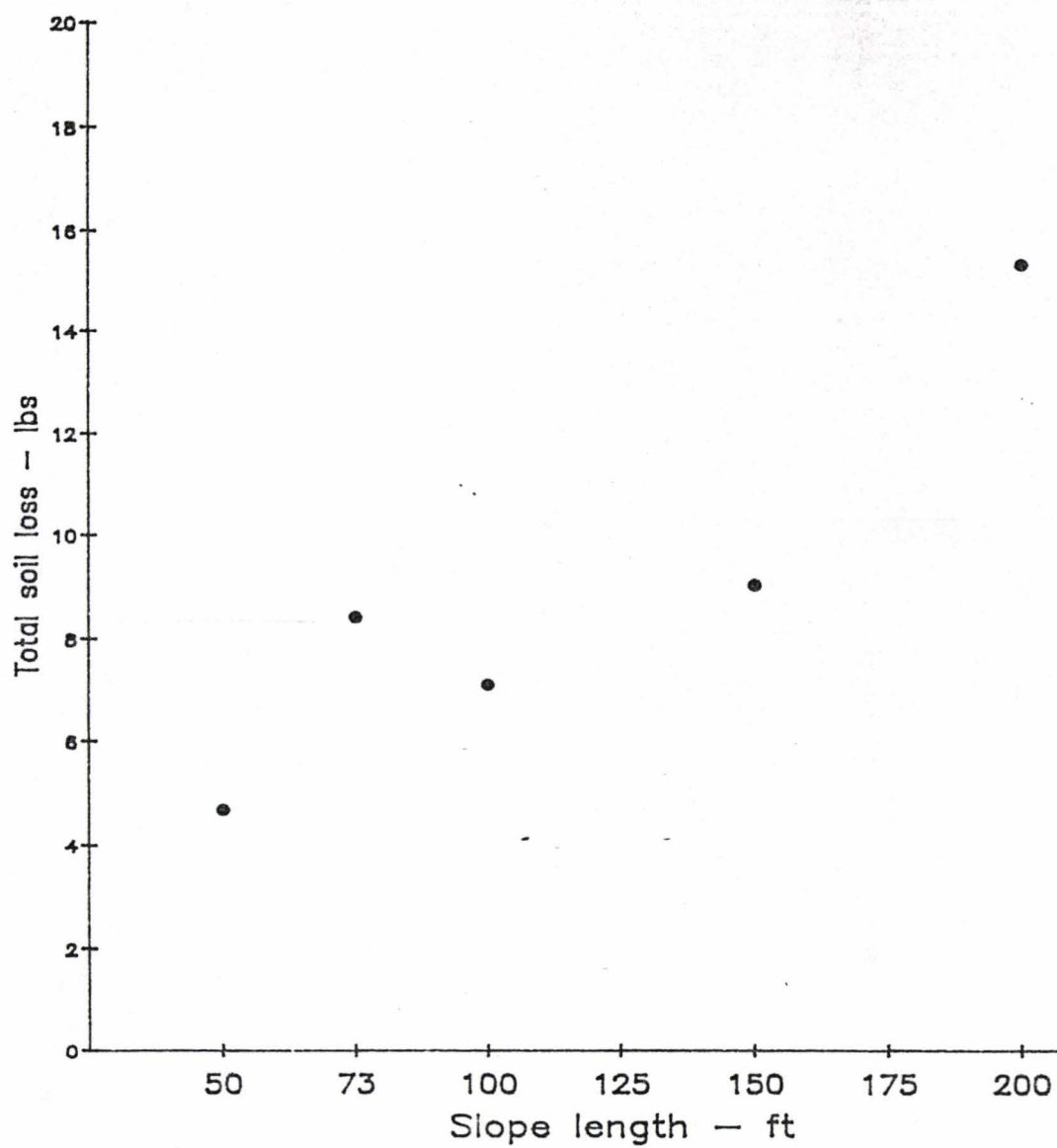


Figure 8 . Total soil loss per plot at the East Mill site.

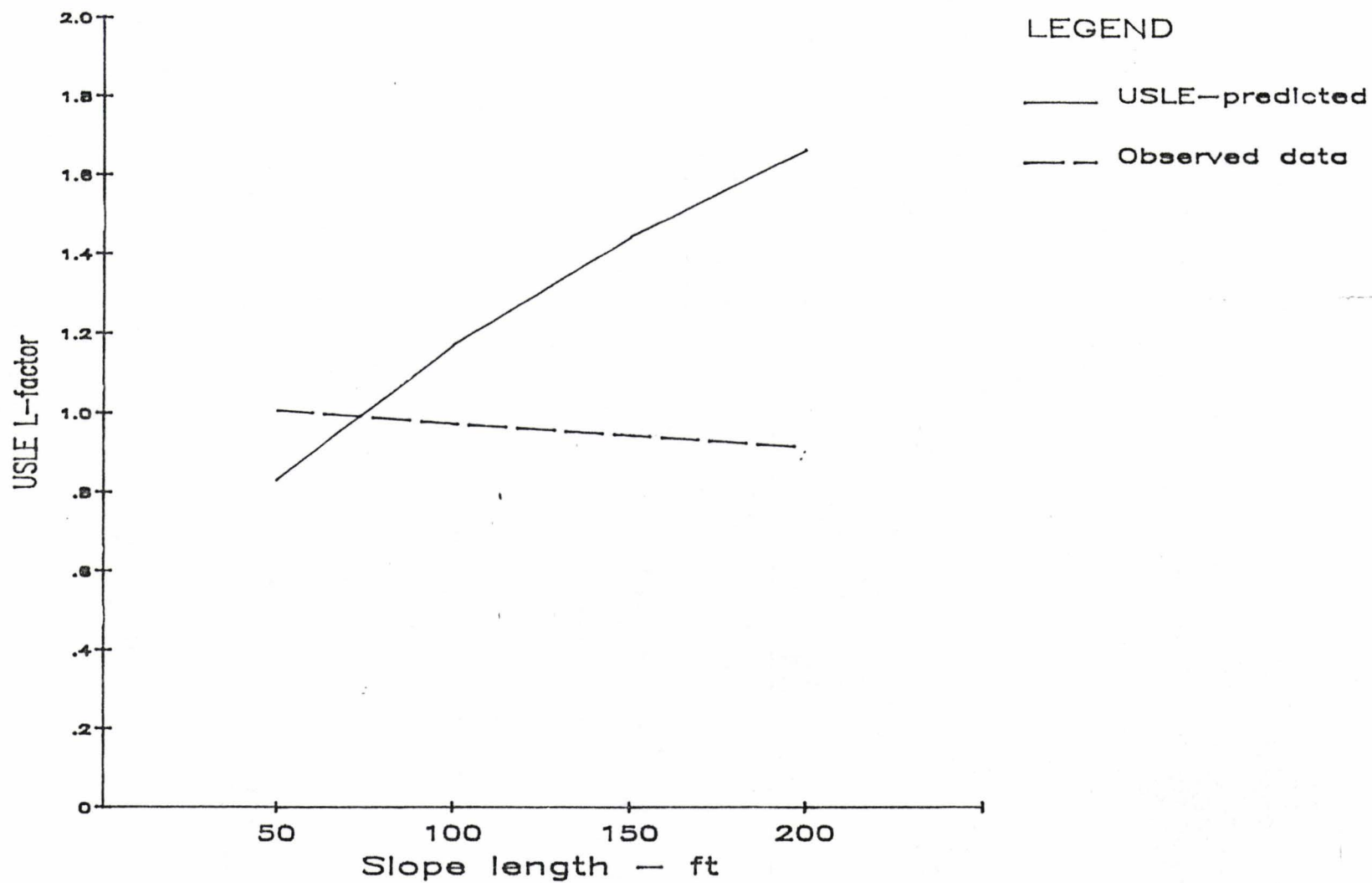


Figure 9.. USLE slope length factors.

## SUMMARY and CONCLUSIONS

Thirteen simulated rainfall events were applied to erosion plots varying in length from 50 to 200 feet (15 to 61 m) on 24 to 33 percent slopes, to determine a relationship between erosion and slope length from phosphate mine waste embankments. A rainfall simulator produced rainfall depths averaging 1.3 inches, (3.3 cm) and intensities averaging 1.6 inches/hour (4.1 cm/hr) on 26 plots at three sites - East Mill, South Maybe, and Champ.

Essentially no erosion was observed at the East Mill or South Maybe embankments. The East Mill site showed a mean soil loss of .136 tons/acre/storm (.305 tonnes/ha/storm), but runoff at South Maybe was too small to be measured. Storms applied on the Champ embankment produced an average of 26.1 tons/acre (58.5 tonnes/ha).

Average peak flows, measured by type-H flumes, differed little between the Champ plots (.043 cfs, .073 m<sup>3</sup>/min) and East Mill plots (.036 cfs, .061 m<sup>3</sup>/min), but mean sediment concentrations were substantially different at the two sites. Mean peak concentrations of East Mill runoff averaged 4,400 parts per million, while Champ's runoff had peak concentrations which averaged 310,000 ppm.

The ratio of runoff to rainfall (Q/P) was calculated for all plots at East Mill and Champ. East Mill plots averaged 64

percent Q/P, and Champ plots averaged 70 percent. Short plots - 50, 73, 90, and 100 feet (15, 22, 27, and 30 m) - had mean Q/P ratios of 67 percent. The 150 and 200-foot (46 and 61 m) plot ratios averaged 33 percent. This suggests that similar hydrologic efficiency was not reached on all plots. It is thought that additional rainfall would have allowed all portions of long plots to contribute to runoff, and hence become more efficient.

The conditions of the embankment surfaces differed considerably from site to site. The East Mill plots were dominated by live vegetation and litter, and showed little bare soil. South Maybe was essentially an erosion pavement - 95 percent of the surface was covered by gravel and rock. Bare soil made up 64 percent of the plot surfaces at Champ. These differences in surface conditions were the most important factors in affecting soil loss from the plots. There was a strong correlation between soil loss and percent bare soil, ( $r = .93$ ), and a strong negative correlation with percent covered by gravel ( $r = -.63$ ). With the exception of the Champ site, the embankments were protected from serious rill erosion by coarse surface materials such as chert, shales, and mudstones.

Slope length appears to have little effect on soil loss from these embankments. Our data showed that there was a negative correlation ( $r = -.5$ ) between slope length and erosion from

these plots. Regression analysis on data from 26 plots shows that the slope of the least-squares trend line was slightly negative, but not significantly different from zero.

Prediction of soil loss from these embankments based on slope length alone would not be advised, as there appear to be other factors which control erosion. Prediction using the USLE ratio  $L = (\lambda / 72.6)^m$ , where  $m = 0.5$ , indicates a positive relationship between slope length and erosion. The results of this study indicate that an  $m$  value of about  $-0.1$  is more appropriate in predicting soil loss from phosphate mine waste embankments.

Results from East Mill show that covering the embankment with topsoil may not be necessary for revegetative success. Erosion measurements made there during the third and fourth years of rehabilitation indicate that erosion is reduced by limiting the amount of exposed soil and allowing the revegetation to occur in mediums dominated by gravel-size material. Based on erosion rates observed at the Champ site, the construction of embankments having large proportions of bare soil should be avoided. Current embankment construction and rehabilitation practices appear to be effective in reducing the soil loss hazard associated with these sites.

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## APPENDIX

The procedure used in determining the least-squares line in Figure 14.

To calculate the L values for each plot, use;

L = the ratio of soil loss from a specified plot length to that from a 72.6 foot plot.

- 1) set the numerator of the ratio equal to soil loss from the plot in question.
- 2) set the denominator equal to the average soil loss from the 72.6-foot plots; in this case, .206 tons/acre.
- 3) calculate the L value for each plot.

Ex.: for East Mill plot 200a-1984,  $L = .162/.206 = .786$ .

- 4) do linear regression with the calculated L values and slope length, and plot the least-squares trend line.

| <u>Plot</u> | <u>Tons/acre</u> | <u>L-value</u> |
|-------------|------------------|----------------|
| 50a         | .181             | .879           |
| 50b         | .140             | .680           |
| 100a        | .077             | .374           |
| 100b        | .164             | .796           |
| 150a        | .040             | .194           |
| 150b        | .225             | 1.092          |
| 200a        | .162             | .786           |
| 200b        | .102             | .495           |
| 150a        | .079             | .383           |
| 150b        | .071             | .345           |
| 200a        | .148             | .718           |
| 200b        | .129             | .626           |

Using the values listed above, the regression equation takes the form;

$$L = 0.7 - .00064 (\text{length}).$$

The least-squares line shown in Figure 14 was adjusted so that  $L = 1.0$  for the 72.6-foot slope length.